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VOL. V OCTOBER, 1951 NO. 4

PACIFIC SCIENCE

A QUARTERLY DEVOTED TO THE BIOLOGICAL AND PHYSICAL SCIENCES OF THE PACIFIC REGION

HAWAII MARINE LABORATORY ISSUE: Hiatt — *The Hawaii Marine Laboratory* • Gosline—*Osteology and Classification of Ophichthid Eels of Hawaii* • Tester — *Distribution of Eggs and Larvae of* Stolephorus purpureus • Hiatt — *Food and Feeding Habits of* Stolephorus purpureus • Matthews — *Origin, Development, and Nature of the Spermatophoric Mass of the Spiny Lobster* • Haneda — *Luminescence of Some Deep-sea Fishes* • Hartman — *Fabricinae in the Pacific* • Bick — *Ecology of Mosquito Larvae of New Guinea* • NEWS NOTES • INDEX

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Although no manuscript will be rejected merely because it does not conform to the style of PACIFIC SCIENCE, it is suggested that authors follow the style recommended below and exemplified in the journal.

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The Hawaii Marine Laboratory[1]

ROBERT W. HIATT[2]

INTRODUCTION

THE COCONUT ISLAND BRANCH of the Hawaii Marine Laboratory was officially opened on April 21, 1951, with an exhibit of research in progress and equipment utilized in the marine sciences. The Hawaii Marine Laboratory is an integral part of the University of Hawaii and consolidates under one name the long-established Marine Biological Laboratory at Waikiki Beach, the biological laboratories devoted to marine sciences on the main campus of the University, and the newly constructed branch at Coconut Island. The Laboratory operates for both teaching and research, with the Waikiki branch and the classrooms and laboratories on the main campus of the University devoted primarily to instruction, and the Coconut Island branch devoted exclusively to research. These new facilities greatly enhance the effectiveness of both the academic program in marine and fishery biology leading to the bachelor's, master's, and doctor's degrees, and the research program in marine sciences of the graduate students and regular staff. Physical separation of instruction and research has now been achieved so that neither interferes with the other. A well-integrated instructional program in marine biology may now be carried out throughout the year at the reef edge at the Waikiki branch, while research projects may proceed without interruption throughout the year at the Coconut Island branch.

The generous loan of unexcelled facilities for marine research by Messrs. Allan Chase, Edwin Pauley, Harold Pauley, Poncet Davis, and Samuel Mosher made it possible to establish the Coconut Island branch. Through funds provided by Mr. Edwin Pauley and the University of Hawaii, this Laboratory and associated ponds and aquaria have been completed and put into operation.

The Laboratory operates throughout the year, but more space is available for visiting investigators during the regular academic year than during the summer period.

Since the Coconut Island branch has been established for strictly research purposes, only persons prosecuting some specific study leading to eventual scientific publication, or an assistant of such a person, will be accommodated. Naturally, staff members of the University of Hawaii will have priority for available space. A cooperative agreement entered into by the University of Hawaii and the University of California for the purposes of mutual assistance in marine research in the central Pacific provides second priority to interested members of the staff of the latter institution. The remaining space is available to other marine scientists. All requests for space must be made on an application form available from the Director. Visiting investigators are welcome and all possible aid will be provided them by the staff of the Laboratory. Such laboratory facilities and housing as are available to visiting investigators bear no fee, except where expendable supplies are concerned. A brochure describing the Laboratory and the regulations for visiting investigators is available from the Director.

COCONUT ISLAND BRANCH

Location: Coconut Island, known to Hawaiians as Moku-o-loe, is situated in the pro-

[1] Contribution No. 8, Hawaii Marine Laboratory.

[2] Department of Zoology and Entomology, University of Hawaii. Manuscript received June 15, 1951.

FIG. 1. Aerial view of Coconut Island, showing the Marine Laboratory (lower center) and the tidal pools (middle left).

tected waters of Kaneohe Bay, about 15 miles from Honolulu, and about 200 yards off the windward shore of Oahu (Fig. 1). Containing a total of 18 acres of land, this verdant island is surrounded by numerous lagoons and pools dredged in the fringing reef. Kaneohe Bay, about 15 square miles in extent, opens broadly to the sea over a protective, elevated reef. The northeast trade winds sweep directly into the bay, thus forcing a rapid exchange of the bay and oceanic waters, which provides for ranges of salinity varying from brackish conditions close to stream mouths to almost normal ocean conditions in the more open areas.

Much of the peripheral region of the bay, especially near the mouths of intermittent streams, is muddy. The organic content of these sandy and muddy areas is high, and it supports an extensive marine fauna. The central part of the bay consists of many channels of varying widths surrounding coral platforms which reach the surface of the water at low tide. Each coral platform is fringed by an extensive growth of corals, principally *Porites compressa* and species of *Montipora*, comprising the finest development of coral growth in the Hawaiian Islands. The eroding tops of these coral platforms contain isolated coral heads interspersed with a fine, silty sand composite. The sides of the channels below 4 fathoms and the bottoms of the channels at an average of 7 fathoms consist of very fine silt. There are many coral heads and intervening sandy areas on the fringing reef platform surrounding Coconut Island, thus providing one of the richest collecting grounds in Hawaii. Contributing greatly to the varied ecological situations in the vicinity of Kaneohe Bay are the true oceanic conditions found just outside the bay, within half an hour's boat trip from the Laboratory.

Fauna and flora: Hawaii is situated at the extreme eastern periphery of the richest faunal area known, the Indo-Pacific. Over 2,000 species of invertebrates and over 500 species of fish inhabit the reef and inshore areas. The Laboratory and its environs offer ideal facilities for studies on all phases of the biology of tropical and subtropical fish, turtles, and invertebrates. Comparatively little is known about the biology of such animals so there is great latitude in the selection of research problems. The zooplankton of the bay waters and the neritic waters just outside the bay is exceedingly varied and abundant in contrast with the oceanic waters farther from shore. The finest oceanic bird rookery in the Hawaiian Archipelago, excepting some of the Leeward Hawaiian Islands, is located just outside Kaneohe Bay on the islet of Moku Manu: a half-hour boat trip from the Laboratory places the observer upon an unparalleled outdoor laboratory for studies on several species of terns, shearwaters, petrels, boobies, and frigate birds.

Hawaiian shores abound in algae of all major groups. Especially abundant are chlorophycean genera such as *Ulva*, *Cladophora* (a variable genus with many representatives), *Caulerpa*, *Codium*, and *Halimeda*. The last four genera offer special possibilities as subjects for physiological research, *Cladophora* because it is large-celled and filamentous, *Caulerpa* and *Codium* because they are unicellular, and the unicellular *Halimeda* because it produces abundant calcareous deposits. Among the Phaeophyceae prominent genera are *Ectocarpus*, *Sargassum*, *Padina*, and *Stictyota*. The red algae are represented by many genera, perhaps the most abundant of which are *Laurencia*, *Rhodymenia*, *Liagora* (mostly calcareous), and the corallines. The agariferous genus *Gelidium* is of special interest. The blue-green algae and the diatoms are, of course, abundant.

Property: The buildings, ponds, docks, and repair facilities occupy the leeward fringe of Coconut Island. In addition to the laboratory itself, there are a residence hall, net house, dock, marine railway, six tidal ponds of varying dimensions and depths (Fig. 2), a battery of large glass-fronted aquaria, and five large partially sunken concrete tanks

FIG. 2. View of some tidal ponds.

with an aggregate capacity of 20,000 gallons. The aquaria and tanks are provided with circulating sea water by a pumping plant separate from that which supplies the system in the laboratory building.

Laboratory and auxiliary buildings: The laboratory building (Figs. 3, 4) faces southeast and borders a large dredged lagoon. The dock is connected to the laboratory structure with a concrete lanai, thus facilitating the transfer of living specimens from the live well of the laboratory's research vessel, the *Salpa*, to the aquarium tables of the laboratory just 30 feet away. Collecting gear and supplies may also be transferred readily to and from the *Salpa*.

The building contains two large laboratories, one for general biological work and one for physiological research, and two smaller general-purpose laboratories (Fig. 5). Fluorescent overhead lights assure adequate illumination. Four to six investigators may be conveniently located in each of the larger laboratories and two in each of the smaller laboratories. In addition to the laboratories there are a work shop, a darkroom, three storerooms, a collection room, and a long concrete lanai on which the aquarium tables are located, thus keeping the sea water out of the laboratories proper. The remainder of the laboratory building consists of living quarters with two large bedrooms, one large dormitory, a kitchen, a combination dining and living room, and bathrooms.

Additional living quarters are located in a second building. These consist of two large bedrooms, one smaller bedroom, bathroom, and living quarters for the caretaker. An electrically operated marine railway which can handle all the smaller craft, and a large storage house for pond screens and other large equipment, complete the present plant.

Laboratory equipment: Running sea water with a salinity of about 35 to 36 parts per thousand is distributed to both the large outdoor aquaria and to the smaller salt-water

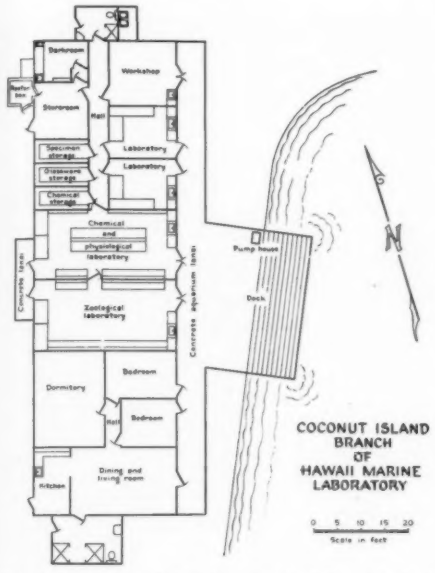

FIG. 3. Floor plan of the laboratory building and dock.

tables on the lanai outside the laboratories. Pumps and motors are arranged in duplicate for each system, with a timer switch which automatically alternates the units. There is no storage or recirculation of sea water, but rather a continuous pumping mechanism. The large pumps are made of cast iron while the lines and valves are of transite, antimony-free lead, and hard rubber. The unit supplying sea water to the smaller laboratory aquaria consists of stainless steel pumps, lead pipes, and hard rubber cocks. The sea water delivered is thus free from contaminants and suitable for the most critical embryological studies. The six large tidal ponds provide unusual space for holding live material, either of small or large size.

Laboratories are supplied with hot and cold running fresh water, 110- to 115-volt alternating current, and bottled-gas outlets. Vacuum and pressure are achieved by portable pump

FIG. 4. View of the laboratory building.

FIG. 5. Interior of a biology laboratory.

FIG. 6. The *Salpa*.

units. Direct current may be supplied by batteries or by an a.c.–d.c. converter.

Refrigeration in the laboratory consists of a deep-freeze unit, a 150-cubic foot reefer box, and electric household-type refrigerators.

Small stocks of routine glassware and reagents are maintained at the laboratory. Certain equipment such as *p*H meters, colorimeters, Warburg-Barcroft apparatus, Van-Slyke apparatus, cathode ray oscilloscope, and other physiological equipment, microscopes, microtomes, balances, cameras, and virtually any other needed item will be supplied by the University from its main campus when the need for them arises. All investigators, however, are requested to submit a detailed list of their needs so that they may be advised of what the Laboratory is in a position to supply.

Field equipment: The opportunities for investigators to conduct research in the field and to observe marine species in their natural environment constitute one of the chief attractions of the Laboratory, and every effort is made to assist investigators on projects requiring this type of approach.

The field equipment includes the 46-foot research vessel, the *Salpa* (Fig. 6), which has a live well with circulating sea water and hoisting gear for dredging, hauling plankton nets, and hydrographic work. Gear such as dredges, seines, and nets of various sorts, traps, plankton nets from small to meter-size openings, Clarke-Bumpus and high-speed quantitative plankton nets, current meters, Nansen bottles with reversing thermometers, bathythermographs, glass-bottom boxes, and diving equipment is available. As with laboratory supplies, investigators are advised to inquire in advance as to their particular requirements.

In cooperation with the Territorial Division of Fish and Game and the Pacific Oceanic Fishery Investigations, larger vessels for work at sea and for deeper dredging are often available to qualified investigators. Such cooperation must be arranged for well in advance.

Library facilities and publications: The proximity of the extensive libraries of the University of Hawaii, Bernice P. Bishop Museum, Hawaiian Sugar Planters' Association Experiment Station, Pineapple Research Institute, and the Pacific Oceanic Fishery Investigations make it unnecessary to maintain a separate library at the Laboratory. At these libraries investigators may secure reference material needed for use at Coconut Island. Microfilm readers are available at the University Library.

The Hawaii Marine Laboratory issues two series of publications. The "Contributions from the Hawaii Marine Laboratory" are technical papers published in suitable journals and are numbered serially. Papers in this series are available to individuals in the fields of their interest, and to institutions which may request individual or all papers of the series. Exchanges are desired. A second series of mimeographed leaflets, entitled "Hawaii

Marine Laboratory News Circular," is sent to interested persons or institutions.

Housing: Housing for four couples and about ten single investigators is available at the Coconut Island residential area. Since all investigators automatically become temporary (although unpaid) members of the staff of the University, other apartments and houses are frequently available on the main campus. These would be more suitable for investigators with families. The rental fee is nominal, and arrangements should be made several weeks or months in advance. Community kitchen and dining room facilities are available at the Laboratory.

Staff: An advisory board deals with general policies and the distribution of working space if the demand exceeds that available. The Board members are Dr. Albert W. Bellamy, Professor of Zoology, University of California at Los Angeles; Mr. Vernon E. Brock, Director, Territorial Division of Fish and Game; Dr. Robert W. Hiatt, Chairman of the Board and Director of the Laboratory, Professor of Zoology, University of Hawaii; Dr. Carl L. Hubbs, Professor of Zoology, Scripps Institution of Oceanography of the University of California; Dr. George F. Papenfuss, Associate Professor of Botany, University of California; and Dr. Albert L. Tester, Professor of Zoology, University of Hawaii.

The resident research staff includes Dr. Albert H. Banner, Associate Professor of Zoology (biological oceanography); Mr. Vernon E. Brock, Lecturer in Fishery Biology (ichthyology, fishery biology); Dr. George W. Chu, Associate Professor of Zoology (parasitology); Dr. Maxwell S. Doty, Associate Professor of Botany (marine botany); Dr. William A. Gosline, Associate Professor of Zoology (ichthyology); Dr. Robert W. Hiatt, Professor of Zoology (marine invertebrates, ecology); Dr. Sidney C. Hsiao, Associate Professor of Zoology (experimental embryology, physiology); Dr. John L. Kask, Lecturer in Fishery Biology (fishery biology); Dr. Donald C. Matthews, Associate Professor of Zoology (invertebrate zoology); Mr. O. E. Sette, Lecturer in Fishery Biology (fishery biology); Dr. Albert L. Tester, Professor of Zoology (fishery biology, biometrics); and Dr. Pieter van Weel, Professor of Zoology (comparative physiology).

The Osteology and Classification of the Ophichthid Eels of the Hawaiian Islands[1]

WILLIAM A. GOSLINE[2]

INTRODUCTION

THE CLASSIFICATION of the eels of the family Ophichthidae is, as Myers and Storey (1939: 156) put it, in the utmost confusion. Their suggested solution, with which I heartily concur, is a sound anatomical study of all the included genera. This cannot be undertaken in the present paper as the family is of circumtropical distribution and many of the genera are unavailable to me. Nevertheless, a rather large and representative group of these eels is present in the Hawaiian Islands. The osteology of the most divergent of these has been investigated in the hope of providing at least a basis for work on ophichthid relationships. The results of this study and of two others already completed (Gosline, 1950, and in press) have borne out the necessity for the entire realignment of the Ophichthidae which Myers and Storey (1939: 157) predicted.

The taxonomic section of this paper deals with all species of ophichthid eels recorded from the Hawaiian Islands (including Johnston Island). One new genus, one new subgenus, and two new species are described, and a substitute specific name is proposed. These are as follows.

Genus: *Phyllophichthus*
Subgenus: *Schultzidia*
Species: *Phyllophichthus xenodontus*
Caecula (*Sphagebranchus*) *platyrhyncha*
Myrichthys bleekeri (to replace *M. semicinctus*)

The paper is concluded with a brief discussion of the distribution of Hawaiian ophichthids.

However, before dealing with these matters, the use of the name Ophichthidae for this family needs explanation. The genus *Ophichthus* (Thunberg and Ahl, 1789: 5) was corrected by nineteenth-century classicists to *Ophichthys*, and the family was called Ophichthyidae. In recent years ichthyologists have returned to the original spelling of the generic name but have retained the emended form of family name. This is illogical and nomenclatorially incorrect. A more serious difficulty arises from the fact that the first family name proposed for the group is Ophisuridae (M'Clelland, 1844: 211). However, whether or not *Ophisurus* is a valid genus is a moot nomenclatorial question. Consequently I prefer not to use for this family, at the present time, the little-known and possibly invalid name Ophisuridae.

Acknowledgments: I wish to acknowledge assistance received from several persons. To the staff of the Pacific Oceanic Fishery Investigations I am indebted for the use of their X-ray equipment and for permission to go to sea on the fishery research ship "Hugh M. Smith." To my shipmates aboard this vessel I am under obligation for help in collecting fishes at various points in the Hawaiian and Phoenix Islands. I am grateful to Dr. C. H. Edmondson and Mr. C. J. Lathrop for permission to examine the ophichthids in the Bishop Museum. Mr. J. Böhlke has kindly looked up literature regarding the name *Ophisurus*. The duplicate series of fishes from Bikini sent me by Dr. L. P. Schultz has been used for comparative purposes. Dr. E. J. Britten has made photomicrographs of the tails of two specimens for me, and Mr. E. L. Gillespie has shaded several of my illustrations.

[1] Contribution No. 6, Hawaii Marine Laboratory.
[2] Department of Zoology, University of Hawaii.
Manuscript received September 29, 1950.

OSTEOLOGY

The most diverse of the Hawaiian ophichthids were selected for osteological study. In general the heads, branchial arches, and pectoral girdles were stained with alizarin and dissected; in *Brachysomophis henshawi* the right side of the head of the only available specimen (and apparently the third known) was dissected without staining. The bodies of the fishes studied were X-rayed, though some specimens were stained and rather unsuccessfully cleared. The species studied in this manner were as follows:

Subfamily MYROPHINAE

Muraenichthys (*Muraenichthys*) *cookei* (Figs. 3, 10*a*, 12*b*, 13).

Subfamily OPHICHTHINAE

Caecula (*Sphagebranchus*) *platyrhyncha* (Figs. 1, 14*b*,*d*).
Myrichthys maculosus (Figs. 5, 7–9, 15*b*).
Cirrhimuraena macgregori (Figs. 6, 10*b*, 16).
Leiuranus semicinctus (Figs. 4, 17*c*).
Brachysomophis henshawi (Figs. 2, 18).

LATERAL LINE SYSTEM OF HEAD AND ASSOCIATED BONES. The pattern of the lateral line system of the head in the Ophichthidae has already been described in considerable detail for "*Ophichthys serpens*" by Allis (1903: 126) and is illustrated here in Figures 1 and 15. It is quite uniform in the species studied.

On the other hand, the degree of development of many of the bones through which the canals pass varies considerably. The canals are enclosed in a series of bony ossicles except where they penetrate the pterotics, frontals, and dentary. These ossicles may be small, separate, bony cylinders; they may be united into more or less elongate tubes; or such a tube may be expanded into a bone of considerable extent. In *Brachysomophis* the ossification of the lateral line system is the most complete (Fig. 2*a*). In that genus the nasal as usual is well developed; in addition the postorbitals form a strong strut for the support of the maxillary, the suborbitals form a tube closely appressed against the maxillary, the preopercle is laminated, and a small

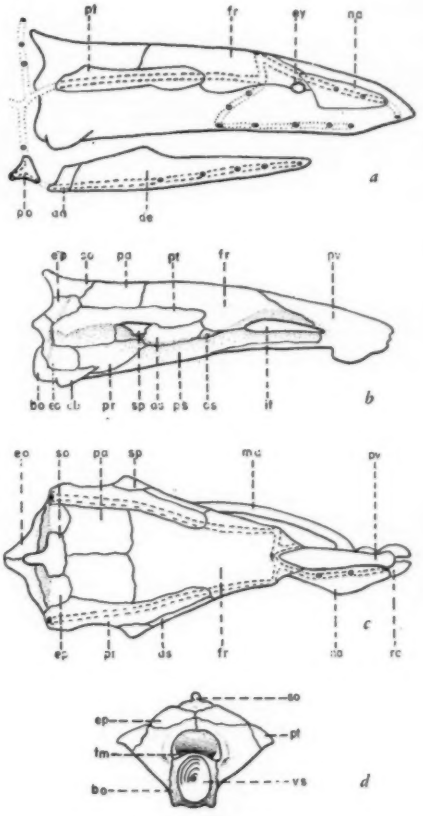

FIG. 1. *Caecula* (*Sphagebranchus*) *platyrhyncha*. *a*, Right side of head, showing lateral line canals and pores. Canals passing through bony ossicles dotted; canals passing through head bones dashed and the outlines of such bones indicated. aa, Articular-angular; de, dentary; ey, eye; fr, frontal; na, nasal; po, preopercle; pt, pterotic. *b*, Right side of cranium. Teeth omitted in this and most of the following figures. as, Alisphenoid; bo, basioccipital; eo, exoccipital; ep, epiotic; fr, frontal; if, interorbital opening; ob, otic bulla; os, orbitosphenoid; pa, parietal; pr, prootic; ps, parasphenoid; pt, pterotic; pv, premaxillary-ethmovomer; so, supraoccipital; sp, sphenotic. *c*, Cranium from above. Lateral line canals of cranial bones drawn in. The nasal (na) is included on the right side, the maxillary (ma) on the left, and the rostral cartilages (rc) in front. Other labels as in Fig. 1*b*. *d*, Skull from rear. Bones labeled as in Fig. 1*b*. fm, Foramen magnum; vs, socket for centrum of first vertebra.

lacrymal appears to be developed. In other genera examined the circumorbitals are reduced to a series of ossicles enclosing the infraorbital canal, and the preopercle is usually almost rudimentary.

OPERCULAR APPARATUS. The opercular apparatus shows various degrees of reduction in the ophichthids examined. In general, the body of the operculum lies mostly or entirely below its articular facet, though it projects upward to a considerable extent in *Brachysomophis* (Fig. 2*a*) and, to some extent, in *Caecula*. The suboperculum and interoperculum are wedge-shaped bones, but in *Muraenichthys* the suboperculum (Fig. 3*a*) sends out a backward projection that encloses the lower edge of the operculum. The preoperculum is moderately developed in *Brachysomophis*, *Leiuranus*, and *Cirrhimuraena*, or is reduced to a tube for the lateral line canal in *Muraenichthys* and *Caecula*. In general, it may be said that the opercular system of *Brachysomophis* is the least, and that of *Muraenichthys* the most, specialized (or degenerate).

SUSPENSORIUM. The suspensorium of *Muraenichthys* (Fig. 3*a*) differs from that of the other species examined in being somewhat forwardly inclined. In all, the palatopterygoid is a laminar bone more or less loosely attached to the hyomandibular and quadrate posteriorly, and by ligament to the maxillary laterally and the skull mesially.

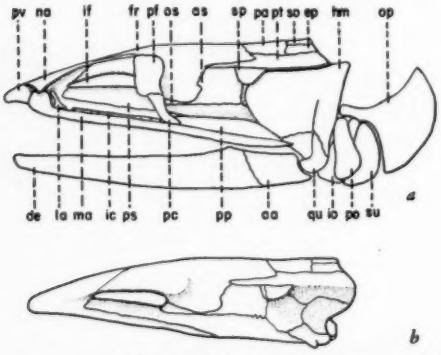

FIG. 2. *Brachysomophis henshawi*. *a*, Bones of left side of head. hm, Hyomandibular; ic, infraorbital canal; io, interopercle; la, lacrymal?; ma, maxillary; op, opercle; pc, enlarged postorbital ossicle; pf, postfrontal; po, preopercle; pp, palatopterygoid; qu, quadrate; su, subopercle. Other labels as in Fig. 1*b*. *b*, Skull from left. Bones as in Fig. 1*c*.

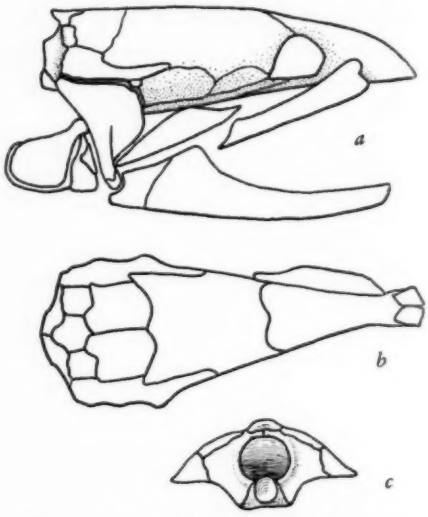

FIG. 3. *Muraenichthys* (*Muraenichthys*) *cookei*. *a*, Head bones from right. Bones as in Fig. 2*a*. *b*, Skull from above. Nasal included on left side. Bones as in Fig. 1*c*. *c*, Skull from rear. Bones as in Fig. 1*d*.

LOWER JAW. The lower jaw is inferior to the upper except in *Brachysomophis* (Fig. 2*a*) where it projects and, like the upper, bears large, sharp canine teeth.

MAXILLARIES. The maxillaries articulate at a more or less variable distance from the tip of the rostrum, far forward in *Brachysomophis* (Fig. 2*a*), more posteriorly in the others. Usually the dentigerous part of the maxillaries terminates well forward of the highest part of the dentary, though an ossified ligament may extend farther back. In *Brachysomophis*, however, the maxillary is a long, toothed bone extending back almost to the level of the lower jaw articulation; it is supported above, as already noted, by the postorbitals.

Another type of jaw specialization is found

in *Leiuranus*. Here the two maxillaries have moved toward each other across the roof of the mouth until their forward ends abut against one another (Fig. 4*b*).

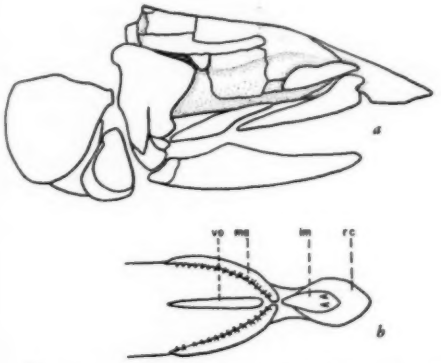

FIG. 4. *Leiuranus semicinctus*. *a*, Head bones from right. Bones as in Fig. 2*b*. *b*, Bones of roof of mouth from below, semidiagrammatic. Teeth indicated. im, Intermaxillary area of premaxillary-ethmo-vomer; ma, maxillary; rc, rostral cartilage; vo, vomerine area of premaxillary-ethmo-vomer.

SKULL. In the cranium of the species examined the greatest difference is between *Myrichthys* and the others. In *Myrichthys* (Fig. 5) the snout is blunt and rounded and the skull is short and high. The interorbital opening seems to have been compressed from front to rear and is elongate vertically. The orbitosphenoids are large, apparently filling that part of the skull wall left by the withdrawal upward of the frontals. In the other genera the interorbital opening is always longer than high. In those species with especially long, low skulls, e. g., *Caecula platyrhyncha* and *Brachysomophis henshawi*, the opening is almost slitlike, whereas in those with a moderately high skull, e. g., *Muraenichthys cookei* and *Cirrhimuraena macgregori*, it is more rounded. In all but *Myrichthys* the orbitosphenoid appears to be more or less squeezed out externally by the frontals above and the parasphenoid below.

In most of the Ophichthidae the ethmoid projects up over the dorsal surface of the frontals as a subtriangular median wedge (Fig. 1*c*). However, in *Myrichthys* (Fig. 5*b*) and *Muraenichthys* (Fig. 3*b*) the projection is broad and bilobed.

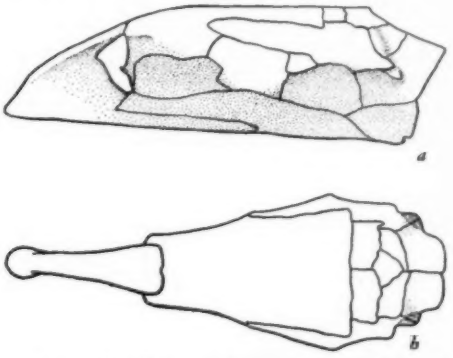

FIG. 5. *Myrichthys maculosus*. *a*, Cranium from left; *b*, from above. Bones as in Fig. 1.

In all the ophichthids examined, auditory bullae are developed as bulges on the ventral surface of the skull. These bullae are formed from parts of the basioccipitals, exoccipitals, and prootics. Axial muscles from the body attach especially to the basioccipitals which, in *Brachysomophis*, form a distinct lobe for this purpose (Fig. 2*b*). Auditory bullae are least prominent in *Cirrhimuraena* (Fig. 6*b*).

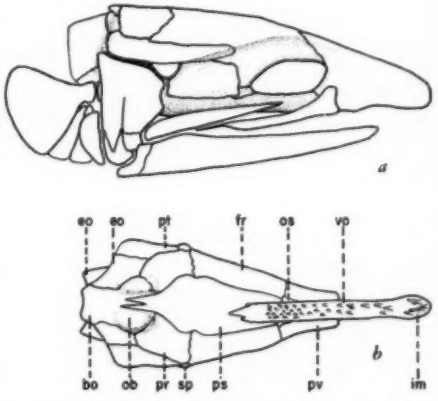

FIG. 6. *Cirrhimuraena macgregori*. *a*, Head bones from right. Bones as in Fig. 2*a*. *b*, Skull from below. Teeth shown. Labels as in Figs. 1*b* and 4*b*.

The skulls of the six genera examined also vary in the distance they project behind the supraoccipital. In *Brachysomophis* the skull is relatively truncate behind; in *Myrichthys*, at the other extreme (Fig. 5), a rather large section of the skull lies behind the supraoccipital.

GILL ARCHES. The gill arches of species of *Muraenichthys*, *Leiuranus*, *Ophichthus*, *Pisodonophis* ("*Ophichthys boro*"), and *Myrichthys* ("*Ophichthys colubrinus*") have been briefly dealt with by Popta (1906). The gill arches of *Myrichthys maculosus* are illustrated in Figure 7.

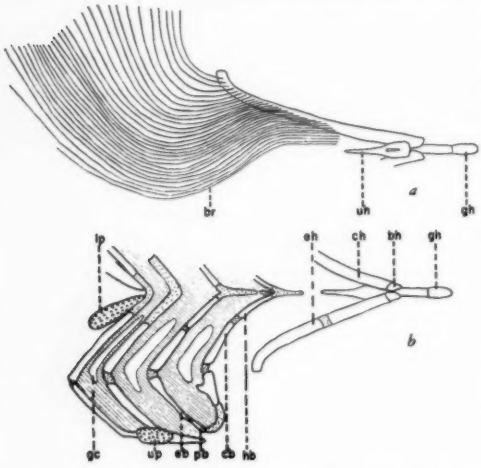

FIG. 7. *Myrichthys maculosus*. *a*, Outline of right side of hyoid apparatus from below. br, Branchiostegal ray; gl, glossohyal; uh, urohyal. *b*, Right gill arches from above, the upper parts opened out. Branchiostegal rays not shown. Cartilage areas stippled. bh, Basihyal; cb, ceratobranchial; ch, ceratohyal; eb, epibranchial; eh, epihyal; gc, gill cleft; gh, glossohyal; hb, hypobranchial; lp, lower pharyngeal; pb, pharyngobranchial; up, upper pharyngeal.

Within the forms examined, the number of branchiostegal rays on one side are as follows: *Caecula platyrhyncha*, 17; *Brachysomophis*, 18; *Cirrhimuraena*, 24; *Muraenichthys cookei*, 26; *Leiuranus*, 28; and *Myrichthys maculosus*, 32. In all of these the branchiostegal rays of the two sides of the head overlap broadly on the midventral line.

The pharyngeal teeth in all of these forms except *Myrichthys* are small, sharp, and depressible; in *Myrichthys* they are blunt and little movable. In all, the upper pharyngeals are shorter and broader than the lower, most notably so in *Brachysomophis*. In *Muraenichthys*, *Leiuranus*, and *Brachysomophis* the lower pharyngeals are elongate and biserial; in the other three genera they are club-shaped to ovate. The number of teeth on a pharyngeal varies from 18 to 34 in the different forms.

PECTORAL GIRDLE. The pectoral girdle seems always to be represented. Judging from X rays it is reduced to a cleithrum and possibly a supracleithrum in *Caecula*. In *Myrichthys* a rudimentary bone which is probably the coracoid (Fig. 8) is embedded in a cartilaginous plate. In *Cirrhimuraena*, scapula, coracoid, and a single actinost are present as well as cleithrum and supracleithrum.

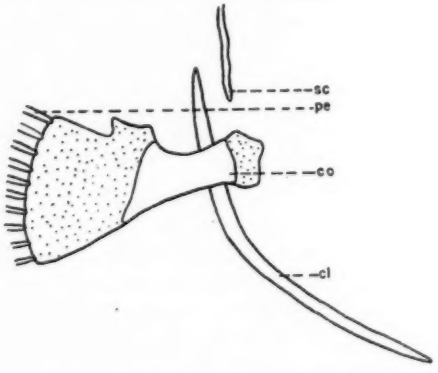

FIG. 8. *Myrichthys maculosus*. Left half of pectoral girdle from inside. Cartilage areas stippled. cl, Cleithrum; co, coracoid?; pe, base of pectoral ray; sc, supracleithrum.

AXIAL SKELETON. Inasmuch as the nature of the vertebral column cannot be properly illustrated in its entirety, and as it has been used as a basis of family definition by Regan (1912: 386), it must be described in a general way. The following account is based primarily on *Myrichthys*, *Brachysomophis*, and *Caecula*. The first centrum is not fused to the skull; it is short, and its neural arch extends backward over the centrum of the second

vertebra (Fig. 9*a*). At about the sixth vertebra the centra develop, ventrally, broad lateral flanges that continue to the anus (Figs. 9*b*,*c*). These are replaced in the caudal vertebrae by strong transverse processes above the haemal arches (Fig. 9*d*). Neural spines are undeveloped except often as small backward projections from a few anterior vertebrae. Epineurals and epipleurals are developed in each anterior segment starting from the anterior part of the column or basioccipital (Fig. 9*a–d*). Pleural ribs are present along most of the column and may be distinctly laminate (Fig. 9*b*,*c*). Epipleurals, epineurals, and pleural ribs extend outward and backward for most of the length of the fish. However, in the tail region these structures are replaced by a series of intermuscular bones, four to each vertebra, extending outward and forward (Fig. 10*b*). *Muraenichthys* lacks such intermuscular bones. Otherwise, the vertebral column in the species studied appears to be rather uniform.

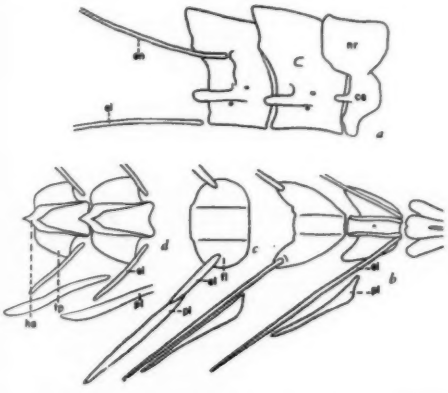

FIG. 9. *Myrichthys maculosus*. *a*, First three vertebrae from right. Epineurals and epipleurals are omitted from first two. ce, Centrum; el, epipleural; en, epineural; nr, neural arch. *b*, Vertebrae 4–6; *c*, vertebra 26; *d*, two anterior caudal vertebrae from below. el, Epipleural; fl, lateral flange of centrum; ha, haemal arch; pl, pleural rib; tp, transverse process of centrum.

The total numbers of vertebrae for several ophichthids are shown in Table 1. Lateral-line pore counts for the body were also made (Table 1) in the hope that these might prove indicators of vertebral number. In a general way, such is the case. The discrepancies between pore counts for the body and the number of vertebrae is probably due, at least in part, to the fact that lateral line pores stop short of the tip of the tail, notably so in *Brachysomophis*. For example, in *Cirrhimuraena macgregori*, with a vertebral count of 181 and with 172 pores, the last pore is over the 171st vertebra.

TABLE 1

VERTEBRAL NUMBERS AND PORE COUNTS IN CERTAIN OPHICHTHIDS

SPECIES	NUMBER OF VERTEBRAE	PORES IN LATERAL LINE
Caecula platyrhyncha	120	120
Brachysomophis henshawi	130	111
Muraenichthys cookei	130	122
Caecula flavicauda	153	153
Leiuranus semicinctus	168	158
Machaerenchelys phoenixensis	169	163
Phyllophichthus xenodontus	170	160
Myrichthys maculosus	178	162
Cirrhimuraena macgregori	181	172
Callechelys luteus	213	208

TAIL. In the past *Muraenichthys* has been placed in a different family from the other genera studied here. The sole reason for this is that *Muraenichthys* has a rudimentary fin around the tip of the tail, whereas the others have the tail protruding as a fleshy point. Osteologically, the difference between the tails of *Muraenichthys* (Fig. 10*a*) and *Cirrhimuraena* (Fig. 10*b*) is less than that between those of *Cirrhimuraena* and *Caecula platyrhyncha*. Rudimentary rays are present around the tails of both *Muraenichthys* and *Cirrhimuraena*; they are merely embedded in flesh in *Cirrhimuraena* (as also in *Myrichthys*). In *Caecula platyrhyncha*, on the other hand, there are no rudimentary rays either around the tip of the tail or elsewhere. It is obvious from this discussion and more obvious from Figure 10 that a separate family cannot be maintained for *Muraenichthys* on the basis of tail structure.

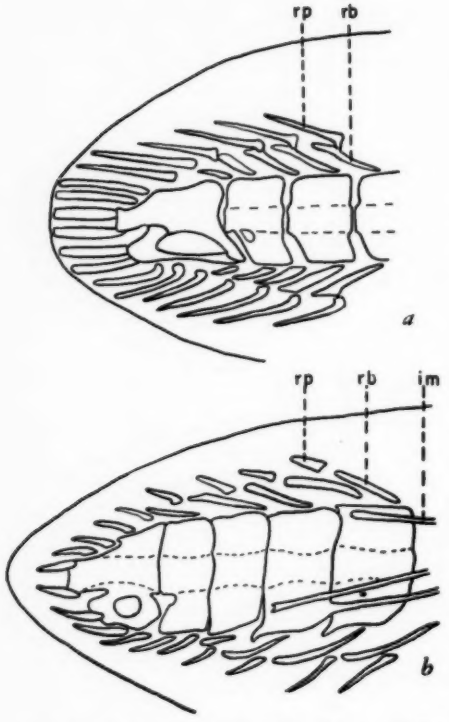

FIG. 10. *a*, Tail of *Muraenichthys* (*Muraenichthys*) *cookei;* b, of *Cirrhimuraena macgregori.* im, Intermuscular bone; rb, basal segment of fin ray; rp, peripheral segment of fin ray.

DIAGNOSIS AND RELATIONSHIPS

Compared with other eel families the most diagnostic features of the Ophichthidae appear to be as follows:

> Dorsal and anal rays either reduced or absent at tip of tail. Posterior nostril below the level of the eye, either on the inside or the outside of the upper lip. Skull not truncate behind. Frontals fused to form a single bone. Suspensorium nearly or quite vertical. Auditory bullae present. Branchiostegal rays of the two sides of the head broadly overlapping on the mid-ventral line. Neural spines rudimentary. Intermuscular bones well developed. Strong transverse processes on caudal vertebrae.

Since the appearance of Regan's excellent paper on eel classification (1912), it has been generally agreed that the Ophichthidae are a specialized offshoot of the congrid stock. Nevertheless, it is necessary here to compare the ophichthids and congrids, partly because no adequate comparison of the two groups exists, and partly to indicate the nature of the specializations in the Ophichthidae.

The ophichthids differ immediately in two superficial characters—the labial nostril and the reduced or absent tail fin. However, these characters are not as significant as they might appear to be.

In the Congridae the posterior nostril opens out in the cheek in front of the eye. A posterolateral deflection of this opening would place it where it occurs in the ophichthid *Caecula flavicauda* (Fig. 14*a*). In those ophichthids that have the narial opening inside the upper lip, the posterior nostril is carried down in a tube (outside the infraorbital canal, as pointed out by Allis [1903]) over the surface of the upper lip and into the mouth. Often the groove behind this tube is still visible externally, as in *Myrichthys* (Fig. 15), but sometimes the tube has been completely fused into the lip. This same specilization of an internal posterior nostril occurs in the unrelated family provisionally called Echelidae (Gosline, 1950).

The reduction or loss of fin rays at the tip of the tail is probably an adaptation to digging, as pointed out by Myers and Storey (1939: 157). That such loss is secondary is shown by the presence of reduced fin rays around the tail of Myrophinae (Fig. 10*a*) and the fin rudiments that remain in certain Ophichthinae (Fig. 10*b*).

Osteologically, *Conger* (Fig. 11) shows numerous characters in which it is undoubtedly more primitive than the Ophichthidae. In most of these it resembles the Anguillidae. However, the Congridae and the Anguillidae differ at once in that the frontals of the Anguillidae are separate, whereas those of the Congridae are fused into a single bone. Pri-

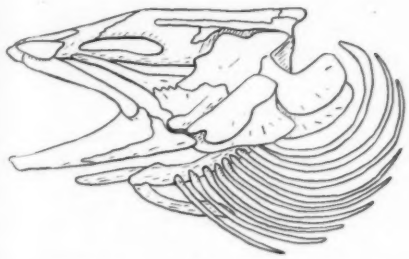

FIG. 11. Head bones of *Conger vulgaris*, after Goodrich.

marily because of this difference, Regan (1912) has, by implication, postulated these two families as being near the starting points of the two main lines of eel evolution. The ophichthids belong in the congrid line.

In *Conger* the suspensorium is well developed and its bones are well integrated, i. e., the palatopterygoid is united by suture with both the quadrate and the hyomandibular. The opercular bones are all large and well developed for eels. The branchiostegals are few (9–9), and those of the two sides do not overlap on the mid-line. The large basihyal projects into the free tongue. These are all primitive characters as compared with the Ophichthidae. *Conger* and *Anguilla* agree in having the skull long and low (this does not seem to me to be a necessarily primitive feature) and in certain associated bone arrangements, i. e., the interorbital opening, alisphenoids, and pterotics are longitudinally elongate, and the orbitosphenoid is small or absent externally. Unlike most ophichthids, but like *Anguilla*, *Conger* has the suspensorium forwardly inclined, and has the intermaxillary and vomerine teeth in an almost continuous series. Unlike most eels that I have examined, including the ophichthids, *Conger* lacks the cross commissure of the lateral line system in the frontals that gives rise to a middorsal pore.

The head skeleton of the Ophichthidae differs from that of *Conger* in four principal ways: (1) there has been a further reduction in the size and strength of certain of the skull bones; (2) the suspensorium has become nearly or quite vertical; (3) the branchiostegal rays have developed a basketlike arrangement on the throat; and (4) an auditory bulla is present.

The bones that have undergone further reduction are the palatopterygoid, the elements of the opercular series, and the preorbital.

It is impossible to say, but seems probable, that the change from a forwardly inclined suspensorium in *Conger* to the nearly vertical one of the Ophichthidae is functionally related to the inferior mouth of most ophichthids. At any rate, in *Conger* much of the adductor muscle of the mandible runs upward and backward to attach to an aponeurosis on the posterodorsal angle of the skull. In the Ophichthidae (with a vertical suspensorium and a more posterior articulation of the mandible) the adductor muscles run more directly up over the skull, and the posterodorsal crest of *Conger* is reduced or totally absent. In addition, the opercular musculature, which attaches to the rear of this same crest in *Conger*, is much reduced in the Ophichthidae. Thus, the skull of the ophichthids, instead of ending posteriorly in an acute edge, usually tapers off more or less gradually into the vertebral column.

Certain other changes in the head skeleton appear to be related to the backward displacement of the quadrate in ophichthids. The maxillary, the posterior end of which abuts against the dentary in *Conger*, usually falls far short of this bone in ophichthids and, except in *Brachysomophis*, is attached to the mandible only by a long, slender, and sometimes ossified ligament. Also, in ophichthids, the palatopterygoid has lost its importance as a strut between the suspensorium and the skull, and has become more or less reduced and disarticulated.

In *Conger*, with forwardly suspended jaw and moderately well-developed opercular apparatus, the gill arches lie largely below the skull, and the gill openings are less than a skull length behind. In ophichthids, on the other hand, the gill arches lie mostly behind

the skull, and the gill openings are more than a skull length from its posterior border. The peculiar basketlike arrangement of the branchiostegal rays has doubtless been developed in ophichthids to shield this otherwise unsupported area of the gill arches. It seems anomalous that a similar arrangement has not been developed in other eel families with posteriorly placed gill arches.

The auditory bulla, though variable in the Ophichthidae, is always present. No trace of this structure is visible externally in the skull of *Conger*.

The pectoral girdle is less degenerate (hence more primitive) in *Conger*, which retains four actinosts, than in ophichthids, in which one actinost at most has been found and in which the girdle may be reduced to a cleithrum and supracleithrum.

Regan's chief osteological differentiation (1912) between the Congridae and Ophichthidae lay in the vestigial neural spines of the latter family. In addition, the intermuscular bones of ophichthids are well developed, and the pleural ribs are often laminar.

From this comparison it is plain that the Ophichthidae and *Conger* are very well separated. If other genera of the Congridae or other eel families are more closely related to the Ophichthidae, there is nothing in the literature to indicate it.

Within the Ophichthidae several minor lines of evolutionary development seem to be represented. It seems justified on zoological grounds (as well as from precedent) to remove *Muraenichthys*, subfamily Myrophinae, first (Gosline, 1950). This genus has two primitive features not found in the other genera examined: the dorsal and anal form an externally visible fin around the tip of the tail, and, in *M. cookei* at least, the suspensorium is somewhat forwardly directed. *M. cookei* also has a moderately short skull with roundish interorbital opening, and the ethmoid projects over the frontals as a rather broad, bilobed plate. In these two features *Muraenichthys* disagrees with *Conger* and with all but *Myrichthys* of the Ophichthidae examined.

Within the subfamily Ophichthinae, one specialized group contains *Brachysomophis* and probably also *Ophisurus* (or *Oxystomus*). These two genera have developed, probably *via Ophichthus*, a protruding lower jaw, fanglike teeth, and an extremely long maxillary supported (as in some muraenids) by a strut of postorbital ossicles. These characters are probably all functional adaptations for fish-eating. In other respects (as well as in the low vertebral number) the skull of *Brachysomophis* resembles that of the weak-jawed *Caecula*.

Another group that can immediately be separated from other Ophichthinae contains *Myrichthys* and probably *Callechelys*. *Myrichthys* (Fig. 5) has a relatively short, high skull, vertically elongate interorbital opening, large orbitosphenoid, and broad, emarginate posterodorsal ethmoid projection. In these characters *Myrichthys* resembles *Muraenichthys*, though convergent evolution rather than close relationship would seem indicated. At any rate, *Myrichthys* and *Callechelys* differ from *Muraenichthys* and most other ophicththids in the large number of vertebrae and in having the relatively high dorsal commencing far forward on the head.

The remaining genera studied are all rather similar internally, though a *Machaerenchelys-Leiuranus-Phyllophichthus* group can be easily separated on tooth characters. In these three genera the vomerine teeth are few or absent and are replaced functionally by those of the maxillaries which have moved in toward the center of the upper jaw.

The last three genera to be dealt with are *Caecula*, *Cirrhimuraena*, and *Ophichthus*. Probably these are not closely interrelated, but I cannot place them with other generic groups. *Caecula* itself may be composite, as it is characterized merely by having the fins rudimentary or absent. (Jordan and Evermann [1896: 374] state, on what basis I do not know, that *Sphagebranchus* [=*Caecula*] "is the most simple in structure among the

Ophichthyidae [=Ophichthinae], as *Ophichthus* is probably the most specialized.") *Cirrhimuraena*, except for the fringed lip, seems to be a rather generalized type of ophichthid, possessing, among other things, a better-developed pectoral than any of the other genera examined. *Ophichthus*, as already mentioned, is probably on the evolutionary road to *Brachysomophis*; whether this is a primitive road for ophichthids is undeterminable.

TAXONOMY

Although internal structures must be taken into account in the basic classification of any group, particularly one as secondarily simplified as the eels, the identification and delimitation of genera and species in the group are normally based on external characters. This is particularly necessary in eels, in which the species are all too apt to be represented by unique specimens that cannot well be dissected.

The Ophichthidae in Hawaii may be recognized superficially by the fact that the fin and fin rays around the tip of the tail are either totally absent, or are much reduced as compared with the dorsal and anal fin rays immediately preceding them. In addition, the posterior nostril lies more or less below the eye, either on the inside or outside of the upper lip. The family is divided (Gosline, 1950, and this paper, above) into two subfamilies—the Myrophinae, with small rays visible externally around the tip of the tail, and the Ophichthinae, with the tail protruding as a finless fleshy point beyond the dorsal and anal. Inasmuch as I have no evidence that either of the two subfamilies is polyphyletic, the taxonomy of each will be discussed separately.

MYROPHINAE. The genera of Myrophinae have been dealt with briefly by Myers and Storey (1939) and by Schultz and Woods (1949). However, I have recently shown (Gosline, 1950, and in press) that among the genera mentioned in both of these papers there are representatives of two quite different families. Thus, *Kaupichthys* and *Chilorhinus* (and presumably *Echelus* and *Garmanichthys*) belong in a family which has little except superficial similarity in common with the Myrophinae. Of the remaining genera probably belonging to the Myrophinae, Myers and Storey (1939: 157) list seven, but Schultz and Woods (1949: 170) reduce this number to two—*Myrophis* and *Muraenichthys*. I have already pointed out (Gosline, 1950) that *Garmanichthys bicollaris* Myers and Wade must almost certainly be removed from the genus *Muraenichthys*, as interpreted by Schultz and Woods. But even with *G. bicollaris* removed, some question arises as to whether these authors have not too broadly interpreted the limits of *Myrophis* and *Muraenichthys*. It appears to me that *Muraenichthys* of Schultz and Woods should at least be divided into subgenera, one of which—*Schultzidia*—is described below.

The circumtropical subfamily includes some 25 described species of small eels.

OPHICHTHINAE. The Ophichthinae comprises one of the largest of eel groups. The genera and species of the subfamily have never been adequately revised.

Difficulties of two main sorts have discouraged recent ichthyologists from revising the subfamily as a whole. First, the group is of circumtropical distribution, but is very inadequately represented in collections. Many of the species and a good number of genera have been based on unique specimens scattered among the museums of the world, and many of the species undoubtedly remain uncollected. Second, most of the characters by which more normal fishes are distinguished are lacking in some or all of the Ophichthinae, e. g., fins, scales, and gill rakers. This has resulted in many hopelessly inadequate descriptions which would have to be properly allocated by anyone reviewing the subfamily.

Each of the three most recent treatments of the subfamily *in toto* is more than 80 years old. Kaup (1856), in his synopsis of the apodal fishes, recognized and described a plethora of

genera (22) on completely insufficient, almost whimsical, bases. As all of Kaup's types, so far as I know, have never been re-examined, many of his generic and specific names remain unidentifiable. Bleeker (1865), in a brief paper reviewing the classification of all eel groups, recognized 8 genera of Ophichthinae. Günther (1870) further reduced the genera of the subfamily to 2, but recent workers have recognized many more.

Since Günther, the Ophichthinae has been investigated only piecemeal. Storey (1939) has redescribed the types of most of the species belonging to the genera *Callechelys* and *Bascanichthys*, but no other generic revisions have been attempted recently. On the other hand, the Ophichthinae of various parts of the world have been dealt with in faunistic reports. Most notable of these are probably those of Bleeker (1864) and Weber and de Beaufort (1916) for the Indo-Australian Archipelago and of Jordan and Davis (1892) for America and Europe.

Genera and species of Ophichthinae continue to be described almost every year—some well, many badly. The system of classification within the group—never adequate—is consequently now outdated and chaotic.

The Ophichthinae are found everywhere along the shores of tropical seas. In addition, some of them have been picked up at the surface of the ocean far from land; at least one, *Caecula cephalopeltis*, occurs in fresh water; and one, *Pisoodonophis boro*, is a pest in rice fields (Ramakrishna Ayyar, 1932). Most of the members are moderate to small wormlike forms, though several are large and have fanglike teeth. Most of the group seem to burrow in the sand with their tails. Some of these, e. g., *Callechelys luteus* in Hawaii, usually remain with the head and a small part of the body above the surface of the sand, while others, e. g., *Sphagebranchus platyrhyncha* in Hawaii, seem to live an almost completely subterranean existence, burrowing forward or backward through the sand with great ease and speed.

The account that follows deals with the 9 genera and 13 species of ophichthids known from the Hawaiian Islands, including Johnston Island. Specimens of all the species are either represented in the University of Hawaii Collection or have been examined in the Bishop Museum. Those represented in the University's collection have been illustrated. In the synonymies all Hawaiian records are listed, but those from elsewhere, except for the type, are not.

Certain principal taxonomic characters of the Hawaiian ophichthids are summarized in Table 2.

ARTIFICIAL KEY TO THE HAWAIIAN SPECIES OF OPHICHTHIDAE

1a. A fin with fin rays present, but reduced, around tip of tail. Species less than 18 inches in length; in Hawaiian forms dorsal originating nearer anus than gill openings, and pectoral fins absent. (Subfamily Myrophinae.)

2a. Dorsal commencing over a head length (measured to gill opening) behind anus; body compressed, its depth about 1½ times its width; teeth lacking on intermaxillary (or premaxillary) and vomer (see Fig. 12*a*).

1. *Muraenichthys* (*Schultzidia*) *johnstonensis*

2b. Dorsal commencing within a head length of the anus; body nearly cylindrical; teeth present on intermaxillary and vomer.

3a. Dorsal commencing behind anus; cleft of mouth reaching well behind eye; vomerine teeth in 2 or 3 rows.

2. *Muraenichthys* (*Muraenichthys*) *schultzei*

3b. Dorsal origin over or ahead of anus; cleft of mouth reaching almost to posterior border of eye; vomerine teeth in a single, sometimes irregular, row (see Fig. 12*b*).

3. *Muraenichthys* (*Muraenichthys*) *cookei*

1b. Tip of tail a hard, fleshy point, without fin. (Subfamily Ophichthinae.)

4a. Body without traces of fins anywhere.

5a. Snout more or less elliptical in cross section, without lateral ridges; head (measured to gill opening) contained 15 to 20 times in the extremely elongate body; posterior nostril opening on outside of upper lip (Fig. 14*a*).

4. *Caecula* (*Sphagebranchus*) *flavicauda*

5b. Snout with well-developed lateral ridges, forming a flattened triangle in cross section; head contained about 10 times in body length; posterior nostril opening on inside of upper lip, the opening not visible externally.

5. *Caecula* (*Sphagebranchus*) *platyrhyncha*

4b. Dorsal and anal present, though sometimes low and inconspicuous.
6a. Dorsal commencing well ahead of gill openings. Lower jaw inferior.
7a. Pectorals absent; tail (measured from anus) shorter than trunk (measured from gill openings to anus). Dorsal high, anal low.
6. Callechelys luteus
7b. Pectorals present; tail longer than trunk.
8a. Pectoral short, rounded, its length less than the width of its base; upper lip not fringed.
9a. Color pattern consisting of several longitudinal series of spots on sides.
7. Myrichthys maculosus
9b. Color pattern consisting of a series of about 29 dark saddles of varying depth, but on an average reaching down approximately to the lateral line.
8. Myrichthys bleekeri
8b. Pectoral considerably longer than broad; edge of upper lip fringed.
9. Cirrhimuraena macgregori
6b. Dorsal commencing about over or behind the gill openings.
10a. Lower jaw inferior; upper lip without a series of papillae.
11a. Anterior nostrils with leaf-like appendages (Fig. 17).
10. Phyllophichthus xenodontus
11b. Anterior nostrils without leaf-like appendages.
12a. Body plain. Eye about equal to snout length. (This species, probably from moderately deep water, will be dealt with in a report on the fishes killed by the Mauna Loa lava flow of 1950.)
11. Ophichthidae, new species
12b. Body with well-marked spots or saddles.
13a. Mouth small and distinctly inferior, the snout projecting beyond tip of lower jaw by more than two eye diameters; teeth small, completely lacking on vomer.
12. Leiuranus semicinctus
13b. Mouth large, little inferior, the snout projecting by less than an eye diameter; teeth large, sharp, present on vomer. Dorsal commencing approximately over gill opening.
13. Ophichthus polyophthalmus
10b. Lower jaw somewhat projecting; upper lip papillate or fringed. Teeth long, fang-like; eye well forward of center of cleft of mouth; dorsal commencing well behind gill opening.
14. Brachysomophis henshawi

MURAENICHTHYS Bleeker

As already mentioned, the most recent paper on the genus (Schultz and Woods, 1949) interprets the limits of the genus *Muraenichthys* very broadly, including in it several genera usually recognized as distinct by previous authors. In the same paper, Schultz and Woods describe a species, *Muraenichthys johnstonensis*, which expands still further the limits of the genus as understood by them. It seems to me that *M. johnstonensis* deserves at least subgeneric rank, which it is given here under the name *Schultzidia*.

Schultzidia new subgenus

SUBGENOTYPE: *Muraenichthys johnstonensis* Schultz and Woods (1949: 172).

The species of this subgenus, as Schultz and Woods point out, differ immediately from other species of *Muraenichthys* in totally lacking teeth on the intermaxillary and vomer. Vomerine teeth are usually well developed in the Ophichthidae, and their absence has long been considered a generic character in the group—in *Leiuranus*, even by Günther (1870: 54), Schultz (1943: 14), and others; and in *Ahlia* by Jordan and Davis (1892: 639), Myers and Storey (1939: 158), and Wade (1946: 199). On the other hand, *Ahlia* has been synonymized under *Myrophis*, a genus typically with vomerine teeth, by Parr (1930: 8), Hildebrand (in Longley and Hildebrand, 1941: 17), and Schultz and Woods (1949: 171). The absence of intermaxillary teeth in *Schultzidia* is, so far as I know, unique among the Ophichthidae, though the dentition or

TABLE 2

SYNOPSIS OF CERTAIN PRINCIPAL TAXONOMIC CHARACTERS OF HAWAIIAN OPHICHTHIDAE

SPECIES	DORSAL ORIGIN	PECTORAL	TEETH	UPPER LIP
MYROPHINAE				
Muraenichthys johnstonensis	Behind anus	Absent	Villiform on maxillaries, absent on intermaxillary and vomer	Not fringed
Muraenichthys schultzei	Behind anus	Absent	Granular; mostly biserial on jaws and on vomer	Not fringed
Muraenichthys cookei	Slightly before anus	Absent	Conical; uniserial on vomer and mandible, biserial on maxillary	Not fringed
OPHICHTHINAE				
Caecula flavicauda and *C. platyrhyncha*	Fin absent	Absent	Small, sharp, depressible, and uniserial throughout	Not fringed
Callechelys luteus	Ahead of gill opening; high	Absent	Conical; uniserial in jaws, biserial on vomer	Grooved but not fringed
Myrichthys bleekeri and *M. maculosus*	Ahead of gill opening; high	Short, rounded	Granular; mostly biserial	Grooved but not fringed
Cirrhimuraena macgregori	Ahead of gill opening; low	Elongate	In adult bluntly conical; on jaws biserial, on vomer in a band	Fringed
Phyllophichthus xenodontus	Over pectoral base; low	Elongate	Absent from vomer; in jaws conical, uniserial, those of mandible directed laterally	Grooved but not fringed
Leiuranus semicinctus	Over pectoral base; low	Roundish	Absent from vomer; small, conical, uniserial elsewhere	Grooved but not fringed
Ophichthus polyophthalmus	Over pectoral base	Somewhat elongate	Large, sharp, uniserial throughout	Not fringed
Brachysomophis henshawi	Somewhat behind pectoral base	Roundish	Fang-like; uniserial on vomer and mandible; biserial on maxillary	Fringed or papillate

lack of it in this part of the mouth is undescribed for several of the species of *Muraenichthys*.

Schultz and Woods, apparently from a reexamination of the types, place *M. retropinnis* in the same group with *M. johnstonensis*. There is nothing, however, in Fowler's original description (1934: 277) to indicate whether this placement is correct.

DERIVATION OF NAME: *Schultzidia*, for Leonard P. Schultz, Curator of Fishes, U. S. National Museum.

1. **Muraenichthys (Schultzidia) johnstonensis** Schultz and Woods

Fig. 12*a*

Muraenichthys johnstonensis Schultz and Woods (1949: 172, fig. 1 and tab. 1) (Johnston Island and Bikini Atoll).

MATERIAL EXAMINED: 1 specimen, 160 mm. in total length, from the reef at Midway and 2 specimens, 84 and 102 mm., from Oahu, in the University of Hawaii Collection.

The Midway specimen agrees in all essen-

tial respects with the excellent description of the species given by Schultz and Woods. I can find in the Midway specimen no embedded teeth on the premaxillary, suggested as a possibility by these authors; in fact, an adnate upper lip covers the area in which such teeth might be expected.

The species is known only from the records listed above.

2. **Muraenichthys (Muraenichthys) schultzei** Bleeker

Muraenichthys schultzei Bleeker (1857: 366) (South Java); Fowler and Ball (1925: 5) (Johnston Island); Fowler (1928: 41) (Johnston Island).

MATERIAL EXAMINED: 8 specimens, 77–99 mm., of the 12 recorded by Fowler and Ball and by Fowler from Johnston Island in the Bishop Museum.

Except for the specimens listed above, the species is unknown in the Hawaiian Islands.

3. **Muraenichthys (Muraenichthys) cookei** Fowler

Figs. 3, 10*a*, 12*b*, 13

?Muraenichthys gymnopterus [non Bleeker], Fowler (1928: 40) (Hawaiian Islands).
Muraenichthys cookei Fowler (1928: 41, fig. 9) (Oahu); Schultz and Woods (1949: 172).
Muraenichthys laticaudata, Schultz [in part] (1943: 53); Fowler (1949: 44).

MATERIAL EXAMINED: 10 specimens from Oahu, 1 from Kauai, and 7 from Midway, all in the University of Hawaii Collection; Fowler's type of the species in the Bishop Museum.

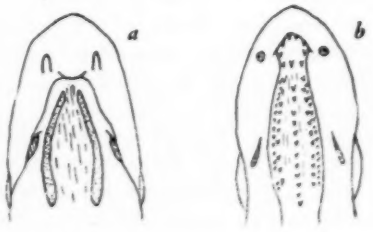

FIG. 12. *a*, Roof of mouth of *Muraenichthys (Schultzidia) johnstonensis*; *b*, of *Muraenichthys (Muraenichthys) cookei*.

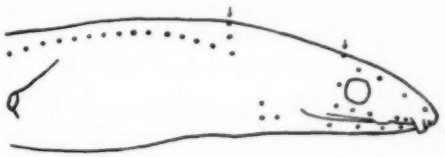

FIG. 13. Head of *Muraenichthys (Muraenichthys) cookei*. As in subsequent figures, the lateral line pores of the head are shown and those of the middorsal line are indicated by arrows.

The distinction between *M. cookei* and *M. laticaudata* is not as clear as one might wish or as Schultz and Woods's key might indicate. In my material of *M. cookei* the dorsal usually commences as much as one-third of a head length ahead of the anus, but is sometimes directly over the anus. In *M. laticaudata* the dorsal usually begins behind, but sometimes over or even slightly before the anus. There are no other readily apparent characters to distinguish the two species.

M. cookei is limited to the Hawaiian Islands and is doubtless a derivative of *M. laticaudata*. The Hawaiian offshoot is not rare. It apparently buries itself in sand-filled pockets on a coralline-rock bottom.

CAECULA Vahl

Vertical fins absent or feebly developed; if present, the dorsal commences behind the level of the gill openings. No pectoral fins in Pacific species.

Subgenus *Caecula:* with at least rudimentary vertical fins.

Subgenus *Sphagebranchus:* wholly finless.

The definition, and consequently the limits, of the genus *Caecula* are agreed upon by no two authors as far as I know. Whether the generic characterization given above is any better than many others previously proposed can be determined only from an examination of the many species in the group.

4. **Caecula (Sphagebranchus) flavicauda** (Snyder)

Table 3 and Fig. 14*a*,*c*

Sphagebranchus flavicaudus Snyder (1904: 516, pl. 2, fig. 4) (from between Maui and Lanai in 21 to 28 fathoms); Jordan and Evermann (1905: 80, pl. 5, fig. 2) (northeast coast of Hawaii in 50 to 60 fathoms).

A fourth specimen of this species in the University of Hawaii Collection is 516 mm. in length and was obtained from shallow water on the coral reef in Hanauma Bay, Oahu.

The posterior nostril of this species opens as an elliptical hole in the outside of the upper lip; the opening is partly covered by a flap (Fig. 14*a*). According to Weber and de Beaufort's classification of the ophichthids (1916: 280) *C. flavicauda* would key out to the genus *Hemerorhinus*. However, *Hemerorhinus* Weber and de Beaufort appears to be one of the less justified generic names in the *Caecula* group.

5. *Caecula (Sphagebranchus) platyrhyncha* new species

Table 3 and Figs. 1, 14*b,d*

?Caecula flavicauda [non *Sphagebranchus flavicaudus* Snyder], Fowler (1928: 47) (Kahala, Oahu; one headless specimen).

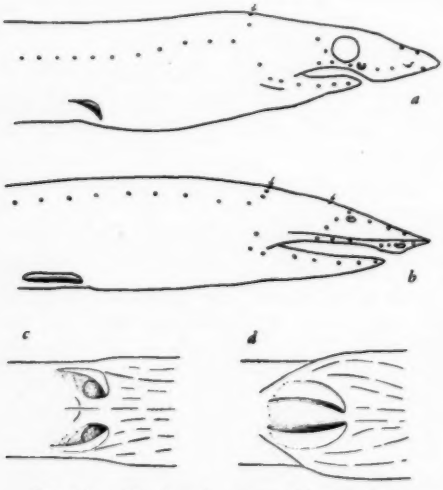

FIG. 14. *a*, Head, and *c*, ventral view, of gill openings of *Caecula* (*Sphagebranchus*) *flavicauda; b* and *d*, same views of *Caecula* (*Sphagebranchus*) *platyrhyncha*.

HOLOTYPE: U.S.N.M. No. 152543, 430 mm. in length, taken in a shallow-water poison station at Hauula Park, north shore of Oahu, T. H., on June 28, 1949, by Gosline and party.

PARATYPES: University of Hawaii No. 316, 10 specimens, 155 to 365 mm. in length, taken with the holotype; University of Hawaii No. 958, 9 specimens, 305–375 mm., taken by Needham and Welsh, July, 1949, at Hanalei, Kauai; U.S.N.M. No. 152544, 3 specimens, 164–355 mm., from a tide pool opposite Pupukea, Waimea coast, Oahu, T. H., collected by Gosline and party, Nov. 22, 1948; Bernice P. Bishop Museum No. 5543, 1 specimen, 455 mm., from Laie, north coast of Oahu, Dec. 17, 1949, collected by Sam Cooke.

A relatively short, sturdy species for the subgenus, with both ends sharply pointed. Snout forming a flattened triangle in cross section, with well-developed lateral ridges; remainder of body more or less cylindrical. Anus somewhat forward of center of length. Eye minute, embedded, and little protruding, but readily visible from the exterior, situated approximately over center of distance from tip of snout to rictus and over forward part of cleft of the inferior mouth. Anterior nostril within a very slightly raised rim on the flattened lower surface of the rostrum, its diameter about equal to the width of the eye. Posterior nostrils opening from the inside of the upper lip into the mouth, slightly before eye, not visible from the exterior. Upper lip with a deep median groove, within which lie the intermaxillary teeth. All the teeth depressible backwards, apparently not implanted in sockets in the jaws, uniserial throughout. About 5 teeth in the intermaxillary, 11 on the vomer, 15 on each maxillary, and about 20 on each side of the lower jaw. Sensory pores of head and body very prominent. Gill openings close together (separated forward by an isthmus about an eye diameter in width), nearly parallel (lines projected forward from their inner surfaces

TABLE 3

PROPORTIONAL MEASUREMENTS (EXPRESSED AS THOUSANDTHS OF THE TOTAL LENGTH) AND PORE NUMBERS FOR HAWAIIAN SPECIES OF *Caecula*

CHARACTER	*Caecula platyrhyncha*							*C. flavicauda*
	HOLOTYPE	PARATYPES, U. H. 316						U. H. 378
Total length in mm.	430	365	315	274	251	207	155	413
Snout to anus	440	424	422	442	433	421	438	538
Snout to gill opening	90	87	86	87	86	90	91	46
Snout to rictus	32	31	31	36	32	34	33	17
Snout to tip of upper jaw	13	13	10	12	14	13	13	9
Snout length	17	15	15	18	17	23	19	10
Eye diameter	3	3	3	4	5	4	5	3
Greatest diameter of gill opening	16	16	19	11	14	14	15	7
Least width of isthmus	3	2	3	4	3	4	6	3
Depth of head	29	29	29	34	30	30	37	17
Depth of anus	21	24	29	27	21	20	19	9
Width of head	28	28	32	29	27	26	36	12
Width of anus	22	22	29	26	23	23	22	11
Lateral-line pores on body	118	121	120	121	121	119	120	153

would meet at an angle of about 25°), and with well-developed membranes covering the outer portions (Fig. 14*d*). Color uniformly pinkish. The specimens have all been taken from sand in shallow water, in which they were originally completely buried.

C. platyrhyncha can be immediately separated from the only other Hawaiian species of the genus by the shorter, more robust body, flat snout, and interior exit for the posterior nostrils. Distinguishing it from other nominal species is more difficult, for a large number of these wormlike, rather characterless eels have been described in a completely undiagnostic way. One such is the subgenotype—*Sphagebranchus rostratus* Bloch (1795)—which has the added feature of being of uncertain origin. (Concerning Bloch's type, Jordan and Evermann, 1896: 373, state: "According to Bloch his type came from the East Indies. Schneider (1801) corrects the locality to 'rivers of Surinam'. We have no means of knowing which record is correct."). However, Bloch states that the anus is in the middle of the body. His plate shows no membranes over the gill opening, and the eye over the middle of the cleft of the mouth. Bloch's species differs from *C. platyrhyncha* in all three of these characters.

There seems to be no described species in Oceania to which *C. platyrhyncha* is closely related. In the Indo-Australian region *Caecula vulturus* (Weber and de Beaufort, 1916: 319), from near Sumatra, appears to be most similar. However, *C. vulturus* is said to be a somewhat slenderer fish with a conical snout and with the posterior nostril opening below the eye. *Sphagebranchus selachops* Jordan and Gilbert from Cape San Lucas, the most similar species from the Eastern Pacific, appears, from Myers and Wade's treatment (1941: 75), to lack membranes over the gill openings.

DERIVATION OF NAME: *platy*, flat; *rhyncha*, snout.

CALLECHELYS Kaup

For the purposes of the present paper the genus may be sufficiently defined as follows: Dorsal and anal fin present, the former commencing ahead of the gill openings. Pectoral fins absent.

6. **Callechelys luteus** Snyder

Fig. 15*a*

Callechelys luteus Snyder (1904: 517, pl. 3, fig. 5) (Molokai); Jordan and Evermann (1905: 86, pl. 8, fig. 1) [on the type]; Storey (1939: 69, tab. 1, fig. 2) [on the type].

Ophichthys marmorata, Günther (1910: 404) (Hawaii).

Callechelys marmoratus, Fowler (1928: 43) (Honolulu market).

MATERIAL EXAMINED: 2 specimens from Oahu, 1090 and 560 mm. in total length. The larger was grabbed by hand by Mr. V. E. Brock as it rested mostly buried in the sand; the smaller swam into a night light.

To enable comparison with the data on the genus assembled by Storey (1939), the following characters of the two specimens mentioned above are given, those for the smaller in parentheses. Greatest depth 40.8 (49.6), head to gill opening 18.5 (18.8), trunk 1.8 (1.9), and tail contained 2.5 (2.3) times in total length; head 10.0 (9.7) and tail 1.3 (1.2) in trunk; snout to rictus 3.6 (3.9) and snout to dorsal origin 2.8 (2.8) in head; distance between gill openings 1.3 (1.2) in length of gill openings; angle of gill openings 130° (125°). In these characters my two specimens check far better with Storey's data on *C. luteus* than on *C. marmoratus* or *C. guichenotii*.

MYRICHTHYS Girard

In the Hawaiian region the genus may be sufficiently distinguished as follows: Dorsal commencing forward of the gill openings. Pectoral present, its base broader than its length. Teeth blunt and granular.

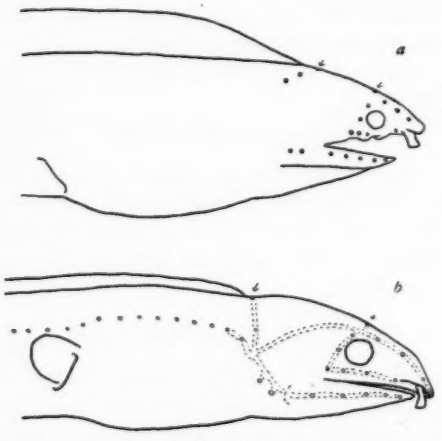

FIG. 15. *a*, Head of *Callechelys luteus*, and *b*, of *Myrichthys maculosus*, with the lateral line system of the head indicated.

7. Myrichthys maculosus (Cuvier)

Figs. 5, 7, 8, 9, 15*b*

Muraena maculosa Cuvier (1817: 232) (European seas?).

Pisoodonophis magnifica Abbott (1861:476) (Hawaiian Islands).

Ophichthus stypurus Smith and Swain (1882: 120) (Johnston Island).

Myrichthys magnificus, Fowler (1901: 494, pl. 18, fig. 3) [on Abbott's type]; Jordan and Evermann (1905: 84) (Hawaiian Islands).

Myrichthys stypurus, Jordan and Evermann (1905: 85, fig. 19) [on Smith and Swain's type].

Ophichthys maculosus, Günther (1910: 40) (Hawaiian Islands).

Myrichthys maculosus, Fowler and Ball (1925: 6) (Johnston Island); Fowler (1928: 43) (Johnston Island and Honolulu).

MATERIAL EXAMINED: 13 specimens from Oahu and 1 from Midway in the University of Hawaii Collection; 1 specimen from Honolulu in the Bishop Museum.

This species seems to be distributed from the Red Sea to Hawaii. It has been taken in the Phoenix (Schultz, 1943: 14) and Line Islands (Fowler, 1927: 5) south of Hawaii, as well as at Johnston Island.

8. *Myrichthys bleekeri* substitute name

Ophisurus fasciatus var. *semicinctus* Bleeker [non *O. semicinctus* Lay and Bennett (1839: 66) non *O. semicinctus* Richardson (1844: 99)] (1864: 64) (Indonesia).

Myrichthys colubrinus, Fowler and Ball (1925: 5) (Johnston Island); Fowler (1928: 42) (in part; the Johnston Island specimens).

MATERIAL EXAMINED: 8, 335–385 mm., of the 12 specimens recorded by Fowler and Ball and by Fowler from Johnston Island, in the Bishop Museum Collection.

These specimens agree well with the diagnosis of this species as given by Schultz (1943: 12).

The records cited are the only ones for the species in the Hawaiian Islands. Schultz (1943: 12) has taken it at Palmyra.

Bleeker's original name is a homonym, for which a substitute is here proposed.

CIRRHIMURAENA Kaup

Dorsal and anal low, the dorsal beginning before, over, or behind the gill openings. Pectorals well developed. Upper lip with a fringe. No canines, the maxillary and vomerine teeth either biserial or in bands.

Cirrhimuraena is here broadly defined. Whether all the species included in the definition are congeneric or even monophyletic is impossible to say without examination of specimens. They appear to fall into three groups, for each of which a generic name has been proposed as follows:

Cirrhimuraena Kaup (1856: 27). Dorsal commencing over or behind gill openings. Pectorals elongate. Eye forward of center of cleft of mouth. Maxillary teeth in bands. Included species: *C. tapeinopterus*, *chinensis*, and *chilopogon*, reviewed in Weber and de Beaufort (1916: 291).

Jenkinsiella Jordan and Evermann (1905: 83). Dorsal commencing well ahead of gill opening. Pectorals elongate. Eye about over center of cleft of mouth. Maxillary teeth biserial. Included species: *Microdonophis macgregori* Jenkins (1904: 422) and *Jenkinsiella oliveri* Seale (redescribed by Herre, 1923: 165).

Calamuraena Whitley (1944:261). Dorsal commencing well ahead of gill openings. Pectorals short, rounded. Eye more or less over center of cleft of mouth. Maxillary teeth mostly biserial. Included species: *Ophichthys calamus* Günther (1870: 74).

9. Cirrhimuraena macgregori (Jenkins)

Figs. 6, 10*b*, 16

Microdonophis macgregori Jenkins (1904: 422, fig. 2) (Maui); Jordan and Evermann (1905: 82, fig. 18) [on the type].

Ophichthus calamus, Fowler (1928: 45) (Maui).

MATERIAL EXAMINED: 4 specimens from Oahu and 2 from Hawaii in the University of Hawaii Collection; 1, recorded above by Fowler, from Maui in the Bishop Museum.

Contrary to the descriptions of Jenkins, Jordan and Evermann, and Fowler, this species does not have the teeth "in a single series on vomer and in jaws." In the larger University of Hawaii specimens, 188–338 mm., the teeth on the vomer are in several series, particularly toward the rear (Fig. 6*b*); those in the jaws are partly uniserial, partly biserial. In the Maui specimen, 131 mm. long, the teeth on the vomer are biserial behind, uniserial in front, and those on the jaws appear as single irregular rows. In other respects my specimens agree with the descriptions cited above. The fringe on the upper lip is somewhat better developed than is indicated in Jenkins' figure, reissued in Jordan and Evermann.

That Fowler erred in synonymizing this species with *Ophichthus calamus* Günther is clearly indicated by Whitley's redescription and figure of the latter species (1944: 261, fig. 6). Actual relationships appear to be closer between *C. macgregori* and *C. oliveri* (Seale) as redescribed by Herre (1923: 165, pl. 2, fig. 2). However, *C. oliveri* is said to have the "vomerine teeth in two rows, merging into one row posteriorly." Herre's plate shows the pectorals as tapering to a point, which also is not true of *C. macgregori*.

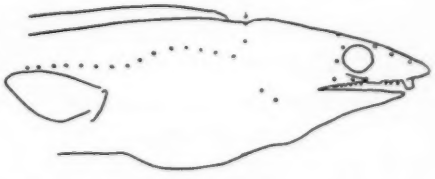

FIG. 16. Head of *Cirrhimuraena macgregori*.

PHYLLOPHICHTHUS new genus

GENOTYPE: *Phyllophichthus xenodontus*, new species.

Head and body subcylindrical, becoming compressed toward tip of tail. Anus about at center of length. Dorsal and anal low, discontinuous around tip of tail which protrudes as a fleshy point. Dorsal commencing over rear of pectoral bases. Pectorals well developed, elongate. Gill openings round orifices opening onto lower part of pectoral bases. Branchiostegal rays numerous, those of the two sides overlapping. Mouth inferior to the long, tapering snout. Anterior nostrils with posterior borders extending downward into leaflike appendages. Posterior nostrils opening into mouth under a broad, infolded flap which is delimited on the outside of the upper lip as a groove below the anterior border of the eye. Two rows of conical teeth on the intermaxillary plate. A single row of smaller teeth on the inner border of each maxillary. No vomerine teeth. Mandibular teeth large, uniserial, well outside of the maxillary teeth, and projecting directly laterally.

Both the leaflike appendages of the anterior nostrils and the dentition of this genus will distinguish it from all other ophichthids. Nasal appendages, though common in the Muraenidae, are little developed elsewhere in the family Ophichthidae, though flaring, tubular nares are indicated for *Chlevastes* by Aoyagi (1943?: 16, fig. 5). In dentition *Phyllophichthus* most closely resembles *Leiuranus*, but the latter genus has normal, upright mandibular teeth. *Phyllophichthus* would appear to be a specialized relative of the *Leiuranus-Machaerenchelys* stock.

DERIVATION OF NAME: *phyll*, leaf; *Ophichthus*, the type genus of the family.

10. *Phyllophichthus xenodontus*
new species

Fig. 17*a,b*

HOLOTYPE: University of Hawaii No. 318, 240 mm. in total length, taken in a poison station from shallow water at Hauula Park, Oahu, T. H., June 28, 1949, by Gosline and party.

DESCRIPTION (all measurements given as thousandths of the standard length): Distance from tip of snout to anus 512, to gill opening 96, to dorsal origin 101, to tip of lower jaw 10, to eye 28; greatest depth 31, depth at anus 22; greatest width 25, width at anus 20; eye 11; fleshy interorbital 12; length of nasal flap 7; cleft of mouth 38; greatest diameter of gill opening 9; width of pectoral base 9; and length of pectoral 26.

Pores in lateral line about 160.

Snout long, tapering to a conical point. Eye well developed, its posterior border nearly over rictus. Cleft of the inferior mouth horizontal, long, and narrow. Groove on under surface of snout (in which lie the intermaxillary teeth) extending nearly to tip of snout. Anterior nostrils about at level of tip of lower jaw, close together, their flaps touching one another. Intermaxillary teeth well developed, conical, arranged as 5 pairs in parallel longitudinal rows. About 4 weak teeth on the inner edge of each maxillary before posterior nostril, 4 or more even weaker embedded teeth behind. Lower jaw with a row of some 18 strong laterally directed teeth on each side; these rows not continued forward around the toothless symphysis. Color of

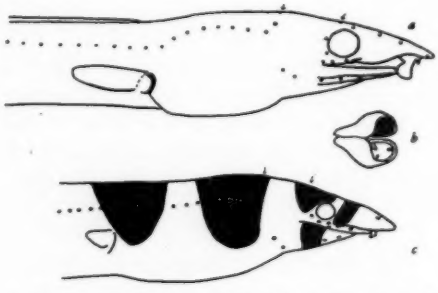

FIG. 17. *a*, Head and *b*, inferior view of anterior nostrils of *Phyllophichthus xenodontus*; *c*, head of *Leiuranus semicinctus*.

head and body in life plain greenish, darker above.

DERIVATION OF NAME: *xen*, strange; *odontus*, toothed.

LEIURANUS Bleeker

Vomerine teeth lacking. Dorsal beginning well behind head. Pectorals small. No nasal appendage.

One species: *Leiuranus semicinctus*.

12.[3] **Leiuranus semicinctus**
(Lay and Bennett)
Figs. 4, 17*c*

Ophisurus semicinctus Lay and Bennett (1839: 66, pl. 4, fig. 4) (Oahu).

Leiuranus semicinctus, Fowler (1901: 494) (Hawaiian Islands); Snyder (1904: 516) (Honolulu); Fowler and Ball (1925: 6) (Johnston Island).

MATERIAL EXAMINED: 2 specimens from Oahu in the University of Hawaii Collection; 2 specimens from Oahu and 2 from Johnston Island in the Bishop Museum Collection.

Among Hawaiian forms, the color pattern of this fish could be confused only with that of *Myrichthys bleekeri*.

OPHICHTHUS Thunberg and Ahl

For purposes of the present paper *Ophichthus* may be defined as follows: Dorsal fin commencing over or behind gill opening. Pectorals present. Conical teeth present on jaws and vomer. Lower jaw somewhat inferior.

13. **Ophichthus polyophthalmus** (Bleeker)

Ophichthys polyophthalmus Bleeker (1864: 43) (Amboina); Fowler (1927: 5) (Kahoolawe); Fowler (1928: 45) (Honolulu market).

Microdonophis fowleri Jordan and Evermann (1904: 164) (Honolulu market); Jordan and Evermann (1905: 82, pl. 6) (Honolulu market); Jordan and Snyder (1907: 208) (Honolulu market).

Microdonophis polyophthalmus, Jordan and Snyder (1907: 208) (Honolulu market).

MATERIAL EXAMINED: 1 specimen in two pieces, recorded by Fowler (1928), from Kahoolawe, in the Bishop Museum.

The teeth in this specimen are large and sharp, in very regular uniserial series on the jaws and vomer. I can find little trace of the fringe on the upper lip described by Jordan and Evermann, and the lower jaw is more inferior than shown on their plate.

BRACHYSOMOPHIS Kaup

Lower jaw protruding beyond the upper. Large canine teeth in the jaws and on vomer. Eye far forward on snout. Upper lip fringed.

The taxonomic problems in regard to *Brachysomophis* have recently been pointed out by Schultz (1943: 17).

14. **Brachysomophis henshawi**
Jordan and Snyder
Figs. 2, 18

Brachysomophis henshawi Jordan and Snyder (1904: 910) (Honolulu); Jordan and Evermann (1905: 84, pl. 7) [on the type]; Fowler (1928: 46) [on the type].

MATERIAL EXAMINED: 1 specimen, without locality but most probably from Oahu, inherited by the University of Hawaii Collection.

DISTRIBUTION OF THE OPHICHTHIDAE IN THE HAWAIIAN ISLANDS

The records of the Ophichthidae in the Hawaiian Islands are in agreement with the

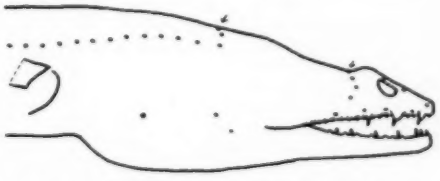

FIG. 18. Head of *Brachysomophis henshawi*. The pectorals of the only available specimen are broken.

[3]For reference to species 11, see key, page 309.

little that is already known of fish distribution in these islands. The predominance of records from Oahu simply reflects the overwhelming proportion of collecting done there. The question remains unsolved whether the Hawaiian fish fauna arrived originally in the low leeward islands and moved from there into the high windward islands after they arose (as postulated for much of the terrestrial biota by Zimmerman, 1948) or whether the present fish fauna came directly to these high islands. That Johnston Island has been a way point in the immigration, and perhaps the emigration, of much, at least of the Hawaiian, fish fauna is indicated by the Ophichthidae, as well as by numerous other groups. The relationship, if any, between the ophichthid eels (and other fish groups) of the Hawaiian chain and those of Wake, as demonstrated by Edmondson (1925) for Crustacea, remains unknown.

The known distribution of Hawaiian ophichthids is shown in Table 4. Such a table may be very misleading for two reasons. (1) It is strongly weighted by the incidence of collecting in the various areas. The low number of recorded species from the leeward Hawaiian Islands, for example, is undoubtedly due to inadequate collecting. Actually, for the areas listed, collecting has probably been done most adequately on the high Hawaiian Islands, less so on the Phoenix and Line Islands, even less on Johnston Island, and least adequately on the leeward Hawaiian group. (2) Such a table may well reflect an author's predilection for "splitting" or "lumping." Of the species listed in Table 4, *Callechelys luteus* and *Muraenichthys cookei* have been and could well be considered synonyms of more wide-ranging species. On the other hand, the Hawaiian specimens of the species here called *Ophichthus polyophthalmus*, described from the East Indies, may well be a distinct species.

Nevertheless, the table does bring out several points. (1) The fact that 7 out of 13 species (and one genus) of Ophichthidae known from the Hawaiian Islands have not been recorded elsewhere indicates the high degree of differentiation of the Hawaiian fish fauna. A similar but probably somewhat lower degree of endemism holds for other fish groups. (2) The species endemic to Hawaii have not yet been taken at Johnston Island. Two species taken at Johnston have not yet been taken elsewhere in the Hawaiian group, but all four species recorded from Johnston are widely distributed in the Indo-West Pacific. This would point—insecurely to be sure—to Johnston Island as a portal for the immigration into Hawaii of wide-ranging Pacific species, but not as a portal for emigra-

TABLE 4

DISTRIBUTION OF HAWAIIAN OPHICHTHIDS

SPECIES	HAWAIIAN ISLANDS			PHOENIX AND LINE ISLANDS	ELSEWHERE
	HIGH	LEEWARD	JOHNSTON		
1. *Muraenichthys johnstonensis*	X	X	X		Bikini
2. *Muraenichthys schultzei*			X	X	Red Sea to Ellice Islands
3. *Muraenichthys cookei*	X	X			
4. *Caecula flavicauda*	X				
5. *Caecula platyrhyncha*	X				
6. *Callechelys luteus*	X				
7. *Myrichthys maculosus*	X	X	X	X	Red Sea to Oceania
8. *Myrichthys bleekeri*			X	X	East Indies
9. *Cirrhimuraena macgregori*	X				
10. *Phyllophichthus xenodontus*	X				
*12. *Leiuranus semicinctus*	X		X	X†	Southern Africa to Samoa
13. *Ophichthus polyophthalmus*	X				East Indies and ?Society Islands
14. *Brachysomophis henshawi*	X				

* For reference to eleventh species, still unnamed, see key, page 309.

† Taken by the author at Hull Island.

tion, i. e., in Simpson's terminology (1940: 148) Johnston would appear to be a primarily one-way "filter bridge" for fishes. This also is borne out in other fish groups. (3) There is no close relationship between the Hawaiian ophichthids and those of the West Coast of America. This, also true of other small fishes, checks well with Ekman's "East Pacific barrier" hypothesis (Ekman, 1935: 105).

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The Distribution of Eggs and Larvae of the Anchovy, *Stolephorus purpureus* Fowler, in Kaneohe Bay, Oahu, with a Consideration of the Sampling Problem[1]

ALBERT L. TESTER[2]

INTRODUCTION

A SMALL SPECIES OF ANCHOVY, *Stolephorus purpureus* Fowler,[3] known locally as the "nehu," is used extensively as livebait in the skipjack (*Katsuwonus pelamis*) fishery of Hawaii. Although the nehu is caught in several different baiting areas throughout the Territory, it is fished most heavily and is taken in largest quantity in Kaneohe Bay, on the east shore of Oahu. In the daytime the fish are caught by surround nets in shallow, turbid water alongshore, often close to the mouths of streams. After dark they are caught by night lighting in deeper and less turbid water farther out in the bay.

Without doubt, the availability of nehu is one of the main factors governing the size of the skipjack catch. In recent years, coincident with an increased fishing effort, there has been an alleged decrease in the availability of nehu in the most important baiting area—Kaneohe Bay. The question has been raised as to whether or not this decrease indicates overfishing of the nehu population.

In 1948, an intensive study of the nehu of Kaneohe Bay was initiated to determine essential biological information which might lead eventually to knowledge of the level of fishing intensity for maximum sustained yield. The present report deals with one phase of this study, namely, the distribution of nehu eggs and larvae throughout the waters of the bay. The investigation must be regarded as preliminary in nature. It was undertaken partly to determine an efficient sampling procedure for future work, and partly to obtain general information on the early life history of the nehu and the distribution of eggs and larvae.

Acknowledgments: The chief responsibility for the field work devolved upon Mr. Lester Zukeran, skipper of the University of Hawaii's research vessel *Salpa*, who located the stations, navigated the ship over the courses, and assisted in the hauling and washing-down of the nets with unending patience and skill.

Two large plankton nets were loaned to us through the courtesy of Mr. Vernon E. Brock, Director of the Division of Fish and Game, Territorial Board of Agriculture and Forestry.

Several graduate students of the University of Hawaii assisted in various phases of the work. Mr. Kenji Ego assisted in Surveys 1 and 2, Mr. Daniel Yamashita in Surveys 1*a*, 1*b*, 2, 3, and 4, and Mrs. Bertha Cutress in Surveys 3 and 4. The monotonous and difficult job of microscopic examination of the plankton samples, including the identification and segregation of the eggs and larvae and the measurement of the larvae, was undertaken with dispatch and efficiency by Mrs. Cutress, assisted on occasion by Mr. Yamashita. Chlorinity and oxygen determinations were made in part by Miss Winnifred Tseu and in part by Mr. Yamashita.

I wish to express my sincere thanks to those

[1] Contribution No. 12, Hawaii Marine Laboratory. Submitted for publication April 2, 1951.

[2] Department of Zoology and Entomology, University of Hawaii.

[3] The status of the generic name has been discussed by Gosline (1951).

individuals who assisted actively in the work and to members of the staff of the Department of Zoology and Entomology, University of Hawaii, who have made helpful suggestions.

PHYSICAL FEATURES OF KANEOHE BAY

Kaneohe Bay (Fig. 1), on the windward (east) shore of Oahu, is about 7 miles in length and about 2 miles in width. It lies in a general northwest-southeast direction and has a total area of about 12 square miles.

For the most part, a continuous but irregularly indented coral reef follows the shoreline and averages about 400 yards in width. It is broken at the mouths of streams by mud flats. The main body of the bay is studded with coral reefs of various sizes and shapes. At low tide these, and also the shoreside reef, are either awash or are covered by about a foot of water; at high tide they are covered by 3 or 4 feet of water. In some places, e.g., the southern sector of the bay, the reefs have been removed by dredging. Deducting the area of the coral reefs and flats from the total, the navigable water area is about 6 square miles.

The southern sector of the bay, which averages about 40 to 45 feet in depth, is protected from the open sea by Mokapu Peninsula. The middle sector of the bay is partially protected from the open sea by coral reefs and by a large sand flat, known as Sand Island, which is partly exposed at some phases of the tide. Within the middle sector, the channels between the reefs average about 40 feet in depth. The northern sector of the bay is also partially protected from the outer sea by sand shallows and coral reefs, although not to the same extent as the southern and middle sectors. Its average depth is less than that of the other two sectors, about 15 to 20 feet.

Thus, apart from a few shallow channels, Kaneohe Bay is virtually cut off from direct interchange with the outer ocean. Although surface water will flow over the shallows and enter the bay, propelled by the strong northeast trade winds, the bay would be expected to have a variety of simple to complex internal circulatory systems, each depending on the configuration of the shoreline, the presence of reefs, the strength of the wind, the phase of the tide, and the amount of fresh water entering the bay from several small streams.

In the southern and middle sectors, the water has a brownish tinge, indicating the presence of silt and, perhaps, plankton. It is quite cloudy alongshore where a strong turbulence is created by the usual onshore wind. In the northern sector, the water close to shore is also somewhat brownish and cloudy. However, the blue ocean water, entering through the main northern channel, impinges on the bay water and, on occasion, forms a definite line of demarcation.

STATIONS AND SURVEYS

Twenty-three stations in representative locations were selected from a chart of Kaneohe Bay, nine (Stations 1 to 9) in the southern sector, eight (Stations 10 to 17) in the middle sector, and six (Stations 18 to 23) in the northern sector (Fig. 1). The stations were not spot locations; rather, they were straight or sinuous courses followed by the research vessel *Salpa* in towing plankton nets. The straight courses were followed in the more open parts of the bay; the sinuous courses were necessary at stations located among the coral reefs. As nearly as possible, the same course was followed at each station during successive surveys.

Four main surveys were undertaken on the following dates: (1) September 6, 7, and 8, 1949, (2) December 27, 28, and 29, 1949, (3) March 16, 17, and 18, 1950, and (4) June 21, 22, and 23, 1950. In each survey, the stations of each sector were worked on successive days. In addition, two interim surveys were made in the vicinity of Station 4 as follows: (1*a*) November 25, 1949, and (1*b*)

FIG. 1. Map of Kaneohe Bay showing place names, sectors, and stations.

December 8, 1949. Casual hauls were also made irregularly throughout the year at various stations in the southern sector.

NETS AND HAULS

Three different plankton nets were used, which are hereafter referred to by the diameter of their mouth openings: 100 cm., 22 cm., and 12.3 cm.

The 100 cm. net had an overall length of about 5 meters. The forward part, 180 cm. in length and 100 cm. in diameter, was made of fish net of 1.5 cm. stretched mesh, and was fastened to the net ring with a 25 cm. strip of canvas. The forward part was lined with an inner skirt of No. 24 grit gauze (0.81 mm. aperture) which was fastened to the canvas forward, but was free aft. The middle part of the net was 100 cm. in length and 100 cm. in diameter. It was made of No. 24 grit gauze and was fastened to the forward part with a 20 cm. strip of canvas. The after part of the net was 190 cm. in length and tapered in diameter from 100 to 9 cm. It was made of No. 40 grit gauze (0.47 mm. aperture) and was attached forward to the middle part and aft to a 9 cm. detachable net band by small strips of canvas. The cod end, 30 cm. in length and 9 cm. in diameter, was also made of No. 40 grit gauze, and was fastened to the net band with a canvas strip.

The 22 cm. net was a simple conical net made of No. 2 Dufour bolting silk (0.35 mm. aperture). Its overall length was 50 cm. The forward part was fastened to the net ring with canvas, and the after end was tied with tape rather than having a detachable cod end.

The 12.3 cm. net was a regular Clarke-Bumpus (Clarke and Bumpus, 1940), with a closing device (which was not used) and a current meter. It was also made of No. 2 Dufour bolting silk.

In the four main surveys two nets, the 100 cm. and either the 22 cm. (Surveys 1, 3, and 4) or the 12.3 cm. (Survey 2), were hauled simultaneously at slow speed just below the surface. The large net was towed from the boom, which was slung out on the starboard side, whereas the small net was towed directly astern. Each haul was of exactly 10 minutes duration. The hauls at each station were made in duplicate, one in one direction (A) and the other in the opposite direction (B) following a reversed course. As nearly as can be determined by timing chips of wood as they passed from bow to stern, the ship's speed varied from 1.8 to 2.2 knots. The slower speeds resulted when towing against the wind, and the faster speeds when towing with the wind.

In the two interim surveys, two identical 22 cm. nets were used, one towed just below the surface and the other at a depth. To avoid the wash of the ship's propeller, the towlines were fastened to a spar which projected horizontally from the port side of the vessel, forward of amidships. The depth was adjusted by fastening lead weights to the net ring and by varying the length of towline. The depth was estimated by calculation, knowing the length of line and the angle of stray. The closing Clarke-Bumpus net was not used for hauls at a depth because of the danger of snagging on the uneven bottom. Further details on haul number, direction, and spacing will be given in a later section of this report.

After each haul, the 100 cm. net was washed with sea water from a pressure hose to concentrate the plankton in the cod end. The smaller nets were jerked upward and downward in the water to accomplish the same purpose. The plankton material was then transferred to quart jars (100 cm. net) or pint jars (22 and 12.3 cm. net), and formalin was added for preservation. To prevent contamination from station to station, the 100 cm. net was towed inside-out, with the cod end removed, between stations. The smaller nets were washed thoroughly in sea water between hauls.

In a few cases, when an exceptionally large catch was made with the 100 cm. net, a small quantity of plankton was lost in attempting to transfer the material from the cod end to

the jar. Loss from this source would not affect the general conclusions appreciably. During the course of each day's operation, there was a steady accumulation of inert organic material on the silk of the 100 cm. net. It was impossible to remove this either by use of the pressure hose or by towing the net inside-out between stations. It could be removed only by scrubbing the net with a brush at the end of the day. This would probably cause a small but progressive decrease in efficiency from station to station within days. During the first 2 days of Survey 1, barnacles on the ship's bottom caused small rips in the silk of the 100 cm. net, which doubtless decreased its efficiency. These were sewn prior to the third day of Survey 1, and snagging of the net was henceforth avoided. The original old, weak grit gauze was replaced with new for Surveys 3 and 4.

Apart from towing the nets in an identical manner and for exactly the same length of time for each haul, no serious attempt at quantitative sampling was made. In Survey 2, meter readings were taken with the 12.3 cm. net. In Surveys 3 and 4, the meter of the 12.3 cm. net was towed behind the boat, and readings were taken for each haul. However, except where indicated, adjusted data are not presented because (1) comparable adjustments are not available for all surveys, (2) the adjusted data, where available, do not differ greatly from the unadjusted data, and (3) the variation between identical hauls at the same place from day to day probably would be of much greater magnitude than the variation induced by slight differences in quantity of water strained from haul to haul on the same day.

PHYSICAL AND CHEMICAL DATA

During each of the main surveys, the temperature of the surface water at each station was recorded to the nearest tenth of a degree Centigrade. In addition, for Surveys 2, 3, and 4, a sample of the surface water at each station was taken and later analyzed for chlorinity (p.p.m.) by the Mohr method. The data are given in Table 1.

In the interim surveys, temperature, chlorinity, and oxygen determinations were made at three depths. The oxygen content (ml./l., adjusted to 20° C.) was determined by the Winkler method. The data are given in Table 2.

EXAMINATION OF PLANKTON SAMPLES

The plankton samples were examined under the binocular microscope by transferring the material, a small quantity at a time, to a Petri dish. Nehu eggs were removed and counted (Tables 3 and 4) according to three categories, "normal," "damaged," and "agglutinated," as defined below. Nehu larvae were removed, counted (Tables 5 and 6), and measured to the nearest tenth of a millimeter by means of a micrometer eyepiece. Standard length was defined as the distance from the tip of the snout to the end of the vertebral column (Table 12). Notes were made on the quantity of plankton in each bottle and on the relative abundance of the dominant organisms.

As the number of nehu eggs per sample was relatively small, the entire sample was examined rather than only a known fraction. This was a time-consuming procedure, usually requiring several man-hours per sample. Segregation of the nehu eggs and larvae was complicated by the presence of large numbers of chaetognaths and ctenophores which had to be teased apart. Despite this difficulty, it is believed that the counts include practically all nehu eggs and larvae in the samples.

Usually most of the eggs were "normal" in appearance—the developing embryo could be seen clearly and was surrounded by a transparent perivitelline space. In some, classed as "damaged," the inner membrane was ruptured and the yolk and shattered embryo had invaded the perivitelline space in varying degree. Obviously these had suffered mechanical injury during capture. In others, classed as

TABLE 1

SURFACE TEMPERATURE AND CHLORINITY IN KANEOHE BAY ACCORDING TO STATION AND SURVEY

STATION	TEMPERATURE (CENT.)				CHLORINITY (P.P.M.)		
	SURVEY 1	SURVEY 2	SURVEY 3	SURVEY 4	SURVEY 2	SURVEY 3	SURVEY 4
1	26.0	23.5	23.9	25.1	18.91	19.19	19.37
2	25.7	23.5	23.9	25.3	18.79	19.22	19.30
3	25.8	23.5	23.9	25.2	18.87	19.22	19.41
4	25.7	23.5	23.8	25.1	18.98	19.32	19.41
5	25.7	23.5	23.7	25.2	19.13	19.38	19.42
6	25.9	23.5	23.5	25.2	19.13	19.32	19.51
7	26.2	23.5	24.0	25.6	19.10	19.38	19.47
8	26.3	23.6	24.4	26.0	19.13	19.32	19.23
9	26.2	23.6	24.0	25.3	19.06	19.35	19.42
10	25.8	23.0	23.8	25.0	18.91	19.14	19.32
11	26.0	22.7	23.8	24.9	18.58	18.95	19.29
12	26.0	23.0	23.8	24.3	18.73	18.93	18.82
13	26.0	22.9	24.0	24.8	18.87	18.97	19.32
14	26.5	23.2	23.8	25.0	19.02	19.14	19.37
15	26.6	23.3	23.8	25.2	19.06	19.34	19.41
16	26.5	23.2	23.9	25.0	19.13	19.32	19.45
17	26.2	23.2	23.9	25.0	19.06	19.21	19.36
18	26.2	23.1	24.2	24.6	19.03	19.23	19.23
19	26.5	23.0	24.1	24.8	18.95	19.26	19.27
20	26.4	23.2	24.4	24.8	19.20	19.30	19.42
21	26.5	23.1	24.7	24.9	19.09	19.21	19.20
22	27.0	23.1	24.8	24.8	19.02	18.99	19.01
23	26.8	23.0	24.8	24.8	19.11	19.36	19.06
Mean	26.2	23.2	24.0	25.0	18.99	19.22	19.31

"agglutinated," disintegration of the yolk and embryo had occurred and the material filling the shell had a whitish color, as if decomposition had been under way for some time.

IDENTIFICATION OF EGGS AND LARVAE

Nehu eggs are oval in shape, bluntly ovoid at the ends, and about twice as long as wide.

TABLE 2

TEMPERATURE, CHLORINITY, AND OXYGEN ACCORDING TO DEPTH DURING SURVEYS 1*a* AND 1*b*

SURVEY	DEPTH	TEMPERATURE	CHLORINITY	OXYGEN
	feet	*centigrade*	*p.p.m.*	*ml./l.*
1*a*	2	23.7	19.29	5.00
	10	23.5	19.40	4.97
	20	23.4	19.33	5.00
1*b*	5	22.8	19.38	5.12
	20	22.6	19.48	5.18
	32	22.5	19.57	5.46

Measurements of 20 eggs from the hauls gave an average length of 1.36 mm. and an average width of 0.61 mm. The yolk contains no oil globule. The shape and size of nehu eggs readily distinguish them from most other round or slightly oval fish eggs found in the plankton. Absence of an oil globule distinguishes them from others of about the same size and shape which belong to an unknown species and which were found on one occasion in a tow taken outside of the bay by Dr. A. H. Banner.

All nehu eggs taken in the tows were at about the same stage of development. The embryo extended approximately one-half to three-quarters of the distance around the yolk; somites were visible in some specimens; the head was taking shape around the lobes of the brain; and the developing eyes were visible but not conspicuous. Less advanced

eggs in the blastodermal cap stage, and more advanced eggs closer to the hatching stage, were not encountered. It has since been found (Yamashita, MS.) that spawning takes place at night, mostly from about 10 P.M. to midnight, and that development from fertilization to hatching occurs in about 24 hours. This explains the rather uniform stage of development of the eggs, for in all tows they were taken during the same 5-hour period of the day—from about 9 A.M. to 2 P.M. Similar observations have been made by Delsman (1929) who pointed out that night spawning and rapid embryonic development are typical of tropical species of *Engraulis* and *Stolephorus* occurring in Javanese waters.

Nehu larvae have been hatched in small shallow dishes of sea water from eggs taken in plankton hauls (Yamashita, MS.). The newly hatched larvae, about 2 mm. in length, have a large, crescent-shaped yolk sac attached to the ventral surface of the body from head to vent. This is gradually absorbed until, at 36 hours after hatching, only a small round ball of yolk remains at the "throat." During these early stages the larvae may be recognized fairly readily by their size, the slender elongated body form, the shape and position of the yolk sac when present, the reticulated appearance of the myotomes, the origin of the dorsal fin fold at the posterior end of the head, and the position of the anus, which is from two-thirds to three-quarters of the distance along the body. At the more advanced stages, the chief diagnostic characters are the slender body form, the reticulated appearance

TABLE 3

NUMBER OF NEHU EGGS PER 10-MINUTE SURFACE HAUL WITH THE 100 CM. NET ACCORDING TO SURVEY, STATION, AND DIRECTION (A AND B), AND SUMMARY

STATION	SURVEY 1		SURVEY 2		SURVEY 3		SURVEY 4		MEAN PER CENT OF SURVEY TOTAL
	A	B	A	B	A	B	A	B	
1.....	–	–	–	–	–	–	5	11	0.16
2.....	–	–	–	–	–	15	–	3	0.07
3.....	233	314	21	107	89	347	6	29	5.12
4.....	1,930	956	383	490	4,180	4,781	127	296	48.63
5.....	769	116	419	332	38	2	262	259	18.41
6.....	30	10	3	3	1	–	3	2	0.28
7.....	2	–	3	2	–	–	8	2	0.17
8.....	–	1	–	–	–	–	53	27	0.82
9.....	6	3	3	2	23	149	123	17	1.97
10.....	–	2	7	2	8	4	–	–	0.15
11.....	–	1	7	5	1	–	–	–	0.16
12.....	3	5	3	0*	5	3	–	–	0.09
13.....	56	172	10	4	55	113	4	2	1.51
14.....	223	117	18	5	14	8	326	150	6.50
15.....	111	113	18	21	8	22	125	121	3.94
16.....	8	8	27	1	73	34	166	122	3.65
17.....	495	141	21	23	31	15	39	30	3.74
18.....	262	143	–	–	2	–	–	–	1.50
19.....	–	–	–	–	–	–	15	11	0.27
20.....	310	205	–	–	–	1	45	33	2.71
21.....	12	–	–	–	–	–	8	1	0.14
22.....	–	–	–	–	–	–	1	–	0.01
23.....	–	–	–	–	–	–	–	–	0.00
Totals....	4,450	2,307	943	997	4,528	5,494	1,316	1,116	100.00

* Part of haul lost.

TABLE 4

NUMBER OF NEHU EGGS PER 10-MINUTE SURFACE HAUL WITH THE 22 CM. NET (SURVEYS 1, 3, AND 4) OR THE 12.3 CM. NET (SURVEY 2), ACCORDING TO SURVEY, STATION, AND DIRECTION (A AND B), AND SUMMARY

STATION	SURVEY 1		SURVEY 2		SURVEY 3		SURVEY 4		MEAN PER CENT OF SURVEY TOTAL
	A	B	A	B	A	B	A	B	
1	–	–	–	–	–	–	1	–	0.17
2	–	–	–	–	–	1	–	–	0.04
3	37	83	3	6	6	22	–	2	7.02
4	244	193	7	26	217	279	11	15	46.14
5	130	15	27	20	5	–	13	17	21.52
6	2	1	–	–	–	–	–	–	0.07
7	–	–	–	–	–	–	1	–	0.17
8	1	–	–	–	–	–	4	3	1.19
9	6	7	1	–	–	14	10	1	3.05
10	–	–	1	1	–	–	–	–	0.54
11	–	–	–	–	–	–	–	–	0.00
12	1	5	–	–	1	–	–	–	0.20
13	4	28	–	–	–	10	–	–	1.25
14	26	9	–	–	–	–	20	6	5.22
15	12	19	–	–	1	1	5	6	2.70
16	1	–	–	–	1	3	9	7	2.87
17	72	18	–	1	3	2	6	4	4.43
18	29	8	–	–	–	–	–	–	0.93
19	1	–	–	–	–	–	–	1	0.19
20	22	16	–	–	–	–	2	5	2.13
21	–	–	–	–	–	–	1	–	0.17
22	–	–	–	–	–	–	–	–	0.00
23	–	–	–	–	–	–	–	–	0.00
Totals	588	402	39	54	234	332	83	67	100.00

of the myotomes, the position of the anus, the projecting lower jaw (up to about 15 mm.), and the lateroventral position of the pectoral fins.

Many of the larvae taken in the tows were damaged to a varying extent. In young larvae the yolk was often torn from the yolk sac, and the fin fold was usually shredded. In older larvae part of the head, including the eyes, was often missing. This complicated the problem of identification. More serious, however, is the possibility that some nehu larvae, broken into fragments, were not recognized as such and were not included in the counts.

VARIABILITY OF THE DATA AND RELATIVE EFFICIENCY OF THE NETS

It will be recalled that, in sampling, two nets were hauled simultaneously, first in A direction and then in B direction at each station. Following the method of Winsor and Clarke (1940), the data may be used to investigate the components of variance and the relative efficiency of the nets. Analyses were made for the egg catches of each survey, using three criteria of classification—stations, haul order, and nets. To approximate normal distributions, the data were transformed to logarithms. The method of analysis is explained by Snedecor (1948: 11.14). Unfortunately, because of the small numbers taken, it was necessary to omit data from many of the stations. The stations included are as follows: Survey 1—3, 4, 5, 13, 14, 15, 17, 18, and 20; Survey 2—3, 4, and 5; Survey 3—3, 14, 16, and 17; and Survey 4—4, 5, 8, 9, 14, 15, 16, 17, and 20. The results are given in Table 7.

TABLE 5

NUMBER OF NEHU LARVAE PER 10-MINUTE SURFACE HAUL WITH THE 100 CM. NET ACCORDING TO SURVEY, STATION, AND DIRECTION (A AND B), AND SUMMARY

STATION	SURVEY 1		SURVEY 2		SURVEY 3		SURVEY 4		MEAN PER CENT OF SURVEY TOTAL
	A	B	A	B	A	B	A	B	
1.....	16	30	1	3	–	5	1	–	3.58
2.....	3	3	2	–	4	8	2	18	5.50
3.....	14	9	4	–	–	3	2	6	2.66
4.....	23	23	14	4	1	7	6	6	6.59
5.....	45	39	26	14	2	2	9	9	10.09
6.....	90	50	25	24	3	2	25	21	14.21
7.....	57	115	15	16	2	15	6	3	14.74
8.....	53	105	5	2	3	–	4	6	7.75
9.....	25	13	5	5	3	4	10	4	5.40
10.....	2	–	7	8	–	5	13	17	5.12
11.....	1	–	18	13	–	1	1	4	3.60
12.....	–	–	7	3*	–	1	4	4	1.81
13.....	–	–	5	1	3	–	3	3	1.91
14.....	2	–	3	2	–	2	43	28	6.14
15.....	–	–	6	1	–	–	33	20	4.38
16.....	–	–	–	2	–	2	6	7	1.72
17.....	3	–	5	–	–	–	13	13	2.40
18.....	1	–	2	4	–	1	1	2	1.10
19.....	–	–	3	2	–	–	1	1	0.61
20.....	–	–	–	–	–	1	–	1	0.38
21.....	–	–	–	–	–	–	–	–	–
22.....	–	–	–	–	–	–	–	–	–
23.....	–	–	–	–	–	1	–	–	0.31
Totals....	335	387	153	104	21	60	183	173	100.00

* Part of haul lost.

As there were obviously large differences in egg catches, both between stations and between nets, the large mean squares for stations and nets were expected. The mean square for haul order was relatively large in Surveys 1, 2, and 4, but includes a large S×H (station by haul) interaction component, and cannot be regarded as generally significant. Moreover, the (geometric) means for A and B hauls (converted from logarithms) do not show a consistent difference from survey to survey:

SURVEY	A	B
1.....	101.4	67.0
2.....	35.2	61.5
3.....	36.7	48.6
4.....	28.5	20.1

Greater interest is centered in the interactions. In all four surveys the S×H interaction is large, and in Surveys 1 and 4 it is highly significant. This demonstrates a lack of consistency in the relative catches of A and B hauls from station to station, due to causes other than chance variation. In all surveys, the S×N (station by net) interaction is relatively large, at least larger than the residual variance S×H×N, but in no case is it statistically significant. It probably includes a real component of variance, σ_{SN}^2, which is of small magnitude. For the present, however, it may be assumed that the catches of the two nets, apart from order of haul, bear a consistent ratio to each other from station to station. The H×N (haul order by net) interaction is small; in fact, it is smaller than the S×H×N interaction in all surveys except the third. In other words, for the same station the catches made in A and B order for each of the two nets are somewhat more consistent than might be expected on the basis of chance

TABLE 6

NUMBER OF NEHU LARVAE PER 10-MINUTE SURFACE HAUL WITH THE 22 CM. NET (SURVEYS 1, 3, AND 4) OR THE 12.3 CM. NET (SURVEY 2) ACCORDING TO SURVEY, STATION, AND DIRECTION (A AND B), AND SUMMARY

STATION	SURVEY 1		SURVEY 2		SURVEY 3		SURVEY 4		MEAN PER CENT OF SURVEY TOTAL*
	A	B	A	B	A	B	A	B	
1.....	3	–	–	–	–	–	–	–	1.51
2.....	–	–	–	–	–	–	–	–	–
3.....	1	–	1	1	–	–	1	–	7.72
4.....	4	12	–	–	–	–	–	–	8.08
5.....	3	9	1	2	–	1	–	1	15.84
6.....	8	4	–	2	–	–	4	2	23.69
7.....	–	3	2	1	–	–	–	–	9.21
8.....	4	4	–	–	–	–	–	–	4.04
9.....	8	1	–	–	–	–	1	–	6.63
10.....	–	–	1	–	–	–	–	–	2.56
11.....	–	–	1	–	–	–	–	–	2.56
12.....	–	–	–	–	–	–	–	–	–
13.....	–	–	–	–	–	–	–	–	–
14.....	–	–	1	–	–	–	3	2	12.98
15.....	–	–	–	–	–	–	1	–	2.08
16.....	–	2	–	–	–	–	–	–	1.01
17.....	–	–	–	–	–	–	–	–	–
18.....	–	–	–	–	–	–	–	–	–
19.....	–	–	–	–	–	–	1	–	2.08
20.....	–	–	–	–	–	–	–	–	–
21.....	–	–	–	–	–	–	–	–	–
22.....	–	–	–	–	–	–	–	–	–
23.....	–	–	–	–	–	–	–	–	–
Totals....	31	35	7	6	–	1	11	5	99.99

* Omitting Survey 3.

variation, i.e., nets towed simultaneously seem to yield partially correlated data.

Before presenting further data to assist in the interpretation of the significant S×H interaction, the relative efficiency of the nets will be considered. The (geometric) mean relative efficiency may be calculated from the logarithmic data. Thus, for Survey 1, the sum of the logarithms of the catches for the 100 cm. net (A and B hauls) is 42.8000, and for the 22 cm. net it is 26.2514. The difference, 16.5486, divided by the number of paired hauls, 18, is 0.9194. The catch ratio, 22 cm. net/100 cm. net, is the antilog of –0.9194 ($\bar{1}$.0806), or 0.1204.

Modifying the formula presented by Winsor and Clarke (1940), the standard error of the ratio involving two nets is given, in logarithms, by

$$\sqrt{\frac{1}{N} \cdot 2(\sigma_{SHN}{}^2 + k_1\sigma_{HN}{}^2 + k_2\sigma_{SN}{}^2)}$$

where N is the number of paired hauls, and k_1 and k_2 are the number of items associated with the respective variance components. In our data (except that of Survey 3), σHN^2 is considered to be 0, rather than a negative quantity. The variance components σSHN^2 and $k_2\sigma SN^2$ constitute the mean square for the S×N interaction. Thus for Survey 1, the standard error of the ratio, in logarithms, is

$$\sqrt{\frac{1}{18} \cdot 2(0.02157)} = 0.0490.$$

The confidence interval, mean ±2 s.e., may be calculated in logarithms and then converted, giving 0.0961 and 0.1509.

The following data have been calculated for each survey:

SURVEY	CATCH RATIO	CONFIDENCE INTERVAL	THEORETICAL CATCH RATIO
1.....	0.1204	0.0961–0.1509	0.0484
2.....	0.0558	0.0300–0.1037	0.0151
3.....	0.0614	0.0338–0.1115	0.0484
4.....	0.0688	0.0552–0.0874	0.0484

In the above tabulation, the theoretical ratios are those for the areas of the net mouths: 100 cm. net, 7,854.0 cm.^{2}; 22 cm. net, 380.13 cm.^{2}; 12.3 cm. net, 118.82 cm.^{2}.

The observed catch ratios differ significantly from the theoretical ratios for all surveys except the third. The smaller nets (22 cm. and 12.3 cm.) are relatively more efficient than the large net (100 cm.). This is in contrast to the results of Winsor and Clarke, although the data are not directly comparable as they were dealing with motile organisms.

The exceptionally large ratio in Survey 1 is doubtless due mostly to loss of eggs from the 100 cm. net when small rips developed, as already explained. The reason for the larger-than-expected ratios in the other surveys is less clear: the straining area of the large net was relatively greater than that of the small nets; the apertures of the mesh in all nets were sufficiently small to retain the eggs, with the possible exception of that of the forward and middle parts of the large net. In these parts it is possible, although not likely, that eggs could have escaped in an end-on position. The efficiency of the large net may have been decreased by loss of plankton during transfer to containers, or by progressive clogging within days, as noted in a previous section.

TABLE 7

ANALYSIS OF VARIANCE OF EGG CATCHES IN SURVEYS 1 TO 4 ACCORDING TO STATIONS, HAUL ORDER, AND NETS

SURVEY	SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
1	Stations (S).....	8	4.28258	0.53532
	Haul order (H).....	1	0.27991	0.27991
	Nets (N).....	1	7.60712	7.60712
	S×H.....	8	1.70812	0.21352**
	S×N.....	8	0.17259	0.02157
	H×N.....	1	0.00371	0.00371
	S×H×N.....	8	0.09480	0.01185
2	Stations.....	2	1.61393	0.80696
	Haul order.....	1	0.17610	0.17610
	Nets.....	1	4.71316	4.71316
	S×H.....	2	0.20601	0.10300
	S×N.....	2	0.10856	0.05428
	H×N.....	1	0.00006	0.00006
	S×H×N.....	2	0.09495	0.04748
3	Stations.....	3	11.85402	3.95134
	Haul order.....	1	0.05958	0.05958
	Nets.....	1	5.87432	5.87432
	S×H.....	3	0.34663	0.11554
	S×N.....	3	0.13537	0.04512
	H×N.....	1	0.05907	0.05907
	S×H×N.....	3	0.11017	0.03672
4	Stations.....	8	3.08473	0.38559
	Haul order.....	1	0.20672	0.20672
	Nets.....	1	12.15801	12.15801
	S×H.....	8	1.00648	0.12581**
	S×N.....	8	0.19387	0.02423
	H×N.....	1	0.00283	0.00283
	S×H×N.....	8	0.10926	0.01366

** Highly significant.

VARIATION IN CATCH WITH ORDER (DIRECTION) OF HAUL

Following Survey 1, Surveys 1*a* and 1*b* were undertaken to investigate in more detail the obviously large differences between A and B hauls at the same station, and also to study variation in egg and larva distribution with depth. To illustrate the differences between A and B hauls it might be noted from Tables 3 and 4 that at Station 4, the 100 cm. net caught 1,930 eggs in the A haul (one direction) and only 956 eggs in the B haul (opposite direction); similarly at the same station, the 22 cm. net took 244 eggs in the A haul and 193 eggs in the B haul. It is the lack of consistency in these differences from station to station which produces the large and significant S×H interaction demonstrated in the preceding section. The differences, which in many cases depart significantly from an expected difference of 0 (using a Chi-square test) may be due to differences in volume of water strained in A and B hauls, to non-random distribution of the eggs, or to both factors.

Surveys 1*a* and 1*b* were both undertaken in the vicinity of Station 4, which had yielded relatively large numbers of eggs in Survey 1. Each A and B haul was of exactly 10 minutes' duration. Two identical 22 cm. nets were towed simultaneously, one just below the surface and the other at a depth.

In Survey 1*a* an attempt was made to run four replicate hauls (I to IV), each replicate including an A and a B haul, and each haul including two depths, thus yielding 16 samples. Each A haul was in a southwesterly direction, with the wind, whereas each B haul was in a northeasterly direction, against the wind. The distance travelled in A hauls, about 3,000 feet, was greater than in B hauls, about 2,400 feet, due to the greater speed attained when travelling with the wind. In the A hauls it was necessary to diverge from the usual Station 4 course to miss the reefs off the southeast side of Coconut Island. Before starting the B hauls, the ship was run along the east shore of the island in order to assume the usual Station 4 course, as illustrated in Figure 2. The resulting data are shown in Table 8, and the analysis of the data, after transformation to logarithms, is shown in Table 9. In the latter, the data were adjusted to an average distance of 2,700 feet in an attempt to overcome one source of variation. This would correct for differences in volume of water strained in A and B hauls only if there were no change in the efficiency of the nets with change in speed.

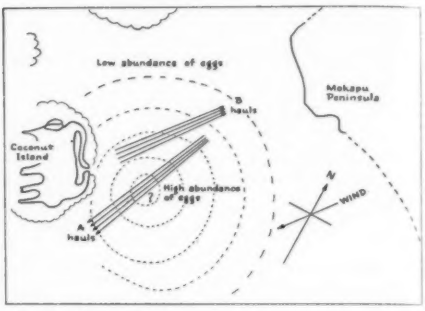

FIG. 2. A portion of the southern sector of Kaneohe Bay in the vicinity of Stations 4 and 5, showing the location of A and B hauls in Survey 1*a*, and indicating the presumed distribution of the eggs (broken isolines).

The adjusted egg catches are as follows:

REPLICATES	A		B	
	surface	*deep*	*surface*	*deep*
I.....	148	130	79	37
II.....	520	456	29	35
III.....	323	302	106	64
IV.....	306	254	56	46

As shown by the analysis (Table 9), there are no significant differences between the (geometric) mean catches for replicates (87, 125, 160, and 119, respectively). However, there is a highly significant difference between the means for haul order or direction (A, 277; B, 52), despite the correction for distance travelled. It is most unlikely that this is due to a change in net efficiency with speed, as the A hauls, at the faster speed, had the higher mean counts; efficiency would be expected to decrease with increase in speed. The analysis also shows a significant R×H

TABLE 8

NUMBER OF EGGS AND LARVAE ACCORDING TO HAUL ORDER (DIRECTION), AND DEPTH FOR SURVEY 1*a* IN THE VICINITY OF STATION 4

HAUL	DEPTH OF TOW		NUMBER OF EGGS		NUMBER OF LARVAE	
	SURFACE	DEEP	SURFACE	DEEP	SURFACE	DEEP
	feet	*feet*				
IA	1	6	165	144	–	1
IB	2	10	70	33	–	3
IIA	1	6	578	507	1	1
IIB	2	10	26	31	–	1
IIIA	1	10	359	336	–	1
IIIB	2	17	94	57	–	1
IVA	1	10	340	282	1	1
IVB	2	17	50	41	1	4
Totals			1,682	1,431	3	13

(replicate by haul order) interaction, i.e., variation other than that due to chance in the differences between A and B catches from replicate to replicate. Both the difference between the catches in A and B hauls and the large R×H interaction can be most plausibly attributed to non-random horizontal distribution of the eggs, as will be explained later.

In Survey 1*b* an attempt was made to cover the area in the vicinity of Stations 4 and 5 in a grid formation with one series of three substation hauls (I to III) spaced at intervals and following a general east-west direction, and a second series of three substation hauls (IV to VI) also spaced at intervals but following a general north-south direction. Each substation was represented by an A and a B haul, and each haul included a surface and a deep sample. In the first series, the A hauls were easterly, against the wind, and the B hauls were westerly, with the wind. In the second series, the A hauls were southerly and the B hauls were northerly, both crosswise to the wind, as illustrated in Figure 3. Deviations from a rectangular grid pattern were necessary because of danger of snagging the deep net on intervening shallows. On one occasion (Haul IIA) the deep net struck the bottom and was torn; it was replaced by another identical net in later hauls. No adjustment was made to compensate for loss of plankton in this haul, but the error introduced will not materially affect the conclusions of either this section or the one which follows. It was estimated that the ship travelled 2,400 feet during A hauls and 3,000 feet during B hauls in the first series, and that it travelled 2,700 feet in both A and B hauls in the second series. The data for each of the 24 samples are given in Table 10, and the analysis of the data, after adjustment to a mean distance of 2,700 feet and transformation to logarithms, is given in Table 11.

The adjusted egg catches are as follows:

SERIES	SUB-STATIONS	A		B	
		surface	*deep*	*surface*	*deep*
1	I	89	69	88	84
	II	21	6	46	44
	III	3	2	17	23
2	IV	191	133	146	124
	V	120	84	141	97
	VI	58	52	53	51

TABLE 9

ANALYSIS OF VARIANCE OF EGG CATCHES IN SURVEY 1*a* ACCORDING TO REPLICATE DOUBLE HAULS, HAUL ORDER (DIRECTION), AND DEPTH

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
Replicates (R)	3	0.14504	0.04835
Haul order (H)	1	2.11768	2.11768**
Depth (D)	1	0.03796	0.03796
R×H	3	0.33144	0.11048*
R×D	3	0.02159	0.00720
H×D	1	0.00669	0.00669
R×H×D	3	0.02470	0.00823

* Significant.
** Highly significant.

TABLE 10

NUMBER OF EGGS AND LARVAE ACCORDING TO HAUL ORDER, AND DEPTH FOR SURVEY 1*b* IN THE VICINITY OF STATION 4

HAUL	DEPTH OF TOW		NUMBER OF EGGS		NUMBER OF LARVAE	
	SURFACE	DEEP	SURFACE	DEEP	SURFACE	DEEP
	feet	*feet*				
IA	2	19	79	61	1	1
IB	1	16	98	93	1	1
IIA	2	19*	19	5*	–	–
IIB	1	16	51	49	3	4
IIIA	2	20	3	2	1	2
IIIB	1	17	19	26	4	4
IVA	1	17	191	133	–	–
IVB	1	16	146	124	–	1
VA	1	17	120	84	–	1
VB	2	18	141	97	–	1
VIA	2	17	58	52	6	1
VIB	2	18	53	51	2	1
Totals			978	777	18	17

* Net hit bottom; some damage to net and loss of plankton.

As shown by the analysis of the data (Table 11), there are significant differences between substations, which are due mostly to the large difference between series. The difference between the (geometric) means for haul order (A, 35; B, 63) is not significant: in Series 1 the means differed to some extent (A, 13; B, 42), whereas in Series 2 they were similar (A, 96; B, 94). However, there is a significant interaction, now designated as S×H (substations by hauls), showing lack of consistency in the differences between A and B hauls from substation to substation. Again, the results may be most plausibly explained on the basis of non-random horizontal distribution of the eggs.

TABLE 11

ANALYSIS OF VARIANCE OF EGG CATCHES IN SURVEY 1*b* ACCORDING TO SERIES, SUBSTATIONS, HAUL ORDER, AND DEPTH

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
Substations (S)	5	4.91036	0.98207*
Between series	1	2.60827	2.60827
Within series	4	2.30209	0.57552
Haul order (H)	1	0.38457	0.38457
Depth (D)	1	0.07549	0.07549*
S×H	5	0.81374	0.16275**
S×D	5	0.04786	0.00957
H×D	1	0.04437	0.04437
S×H×D	5	0.05212	0.01042

* Significant.
** Highly significant.

To explain the foregoing results satisfactorily it is necessary to assume only that there is a focus of abundance of eggs in the vicinity of Station 4, with gradients of decreasing abundance extending outward in all directions. The nature of the egg distribution which is postulated to have occurred during Surveys 1*a* and 1*b* is illustrated in Figures 2 and 3. Transection of the area at various distances from the focus would cause the great variability in catch and would readily account for the observed significant differences and interactions. As will be shown later, the presence of a focus of abundance of eggs in the vicinity of Station 4 is also demonstrated by the results of the general surveys.

It seems likely that non-random distribution of the eggs occurs at all stations. Slightly different gradients of abundance are passed through in making A as compared with B hauls, often causing large differences in the number of eggs caught. A similar situation may also occur in the case of larvae, although the differences between A and B hauls are, in general, less pronounced and persistent. Be-

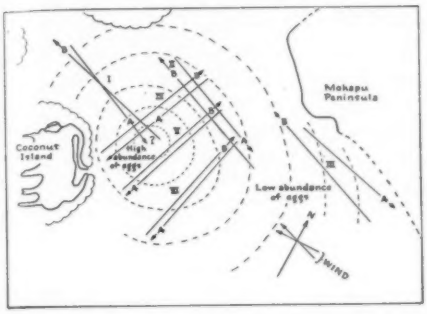

FIG. 3. A portion of the southern sector of Kaneohe Bay in the vicinity of Stations 4 and 5, showing the location of A and B hauls in Survey 1*b*, and indicating the presumed distribution of the eggs (broken isolines).

cause of the small numbers of larvae taken in the samples, a similar detailed analysis of the data was not undertaken.

Obviously, the peculiar non-random distribution of the eggs should be taken into consideration in designing a program of quantitative sampling for future work.

VERTICAL DISTRIBUTION OF EGGS AND LARVAE

The vertical distribution of eggs and larvae was studied only at Station 4 during Surveys 1*a* and 1*b*, the details of which have been discussed in the previous section. Unfortunately, it was not possible to sample efficiently over a range of depth. In analyzing the results (Tables 9 and 11), the surface samples, from 1 to 2 feet, are compared with those at "a depth," the depth ranging from 6 to 17 feet in Survey 1*a* (Table 8) and from 16 to 20 feet in Survey 1*b* (Table 10). The (geometric) mean catches of eggs in the adjusted data may be compared in the following tabulation:

HAULS	SURVEY 1*a*	SURVEY 1*b*
Surface	134	54
Deep	107	41

In both surveys there were more eggs at the surface than at a depth. There were no significant interactions involving depth in either Survey 1*a* (R×D and H×D) or Survey 1*b* (S×D and H×D). The significance of the difference between surface and deep hauls was tested by comparing the mean square for depth with an error term derived by pooling the sums of squares and degrees of freedom for the last three components in each of Tables 9 and 11. The difference approached significance for Survey 1*a* and was significant (P less than 0.05) for Survey 1*b*. It may be concluded that there are slightly more eggs at the surface than at a depth. It seems likely that there is a gradient of decreasing abundance from surface to bottom, although this cannot be affirmed positively from the present data.

The variation of temperature, chlorinity, and oxygen with depth for Surveys 1*a* and 1*b* is shown in Table 2. The results for Survey 1*b*, in particular, suggest that there may be a relationship between the vertical distribution of the eggs and the vertical distribution of these physical factors. Temperature decreases with depth, whereas both chlorinity and oxygen increase with depth. At the present stage of investigation it is idle to speculate as to the nature of the possible relationship.

The numbers of larvae taken in the various hauls of Surveys 1*a* and 1*b* were small. In 1*a*, fewer larvae were caught at the surface than at a depth, whereas in 1*b*, slightly more were caught at the surface than at a depth. No significant change in larva distribution with depth can be demonstrated with the present data.

HORIZONTAL DISTRIBUTION OF EGGS AND LARVAE

It has been shown that there are highly significant differences between the catches of eggs made from station to station, apart from differences between hauls at the same station. Accordingly, in the gross analysis to follow, the count at each station is assumed to be representative of a particular abundance level at each station.

Distribution of Eggs

To show the general distribution of eggs

throughout the bay, the number (A plus B hauls) taken at each station was expressed as a percentage of the total number caught in each survey, and the four percentages for each station were averaged. This gave the data in the last column of Tables 3 and 4. The results for the 100 cm. net are portrayed graphically in Figure 4.

The following tabulation shows the general distribution of eggs according to sector and net:

SECTOR	LARGE NET		SMALL NETS	
	per cent of total	*mean per cent per station*	*per cent of total*	*mean per cent per station*
Southern	75.63	8.40	79.37	8.82
Middle	19.74	2.47	17.21	2.15
Northern	4.63	0.77	3.42	0.57

The results show that eggs were most abundant in the southern sector, less abundant in the middle sector, and least abundant in the northern sector. The results for Surveys 1, 2, and 3 were fairly consistent with the above averages. In Survey 4, however, most eggs were found in the middle sector.

Examination of the temperature and chlorinity data of Table 1 shows no apparent correspondence between their distribution and that of the eggs. For example, the average temperature (four surveys) for the three sectors were respectively 24.7, 24.5, and 24.7°C.; the average chlorinities (three surveys) for the three sectors were respectively 19.23, 19.11, and 19.16 p.p.m.

In the southern sector of the bay, all four surveys showed a peak of abundance of eggs in the vicinity of Stations 4 or 5 (Fig. 4, Tables 3 and 4). Both the interim surveys and casual sampling between surveys indicated the persistence of this peculiar distribution. There is no apparent relationship between the distribution of eggs (Table 3) and the distribution of temperatures and chlorinities in the southern sector (Table 1). The explanation of the focus of abundance of eggs in the northeast part of the southern sector is uncertain. It seems most likely that the eggs are held there in the eddy of a current, but information on this possibility must await a study of the circulation of water in the bay. If it is found that the eggs are held in an eddy system, it must still be discovered whether nehu eggs are accumulated from widespread spawning throughout the sector or whether they result from localized spawning near the center of the eddy.

In the middle sector of the bay, all four surveys showed larger numbers of eggs in the more northerly part, Stations 13 to 17, than in the more southerly part, Stations 10 to 12 (Fig. 4, Tables 3 and 4). Although on the average the maximum concentration was at Station 14, the peak of abundance varied from station to station with survey. For example, the largest number of eggs was encountered at Station 17 in Surveys 1 and 2, at Station 13 in Survey 3, and at Station 14 in Survey 4. This is in contrast to the relatively stable condition found in the southern sector of the bay. Variation in abundance at a station from survey to survey may be related to variation in the number of spawning fish, to variation in the current system in the middle sector, or to both factors. Judging from the topography of the middle sector, the current system would probably vary to a considerable extent with strength and direction of the wind and with phase of the tide.

In the northern sector of the bay, eggs were encountered in fair numbers only during Surveys 1 and 4. In Survey 1 they were relatively abundant at Stations 20 and 18, and in Survey 4, at Stations 20 and 19. On the average, the greatest abundance was at Station 20, which is located in the main ship channel toward the outside reefs. Either no eggs or very few eggs were taken at Stations 21, 22, and 23, which are located among the shoreside reefs in the northernmost part of the bay.

Comparison of Table 1 with Tables 3 and 4 shows no apparent relationship between variation in temperature and chlorinity and variation in egg abundance from station to station within surveys for either the middle or northern sectors of the bay.

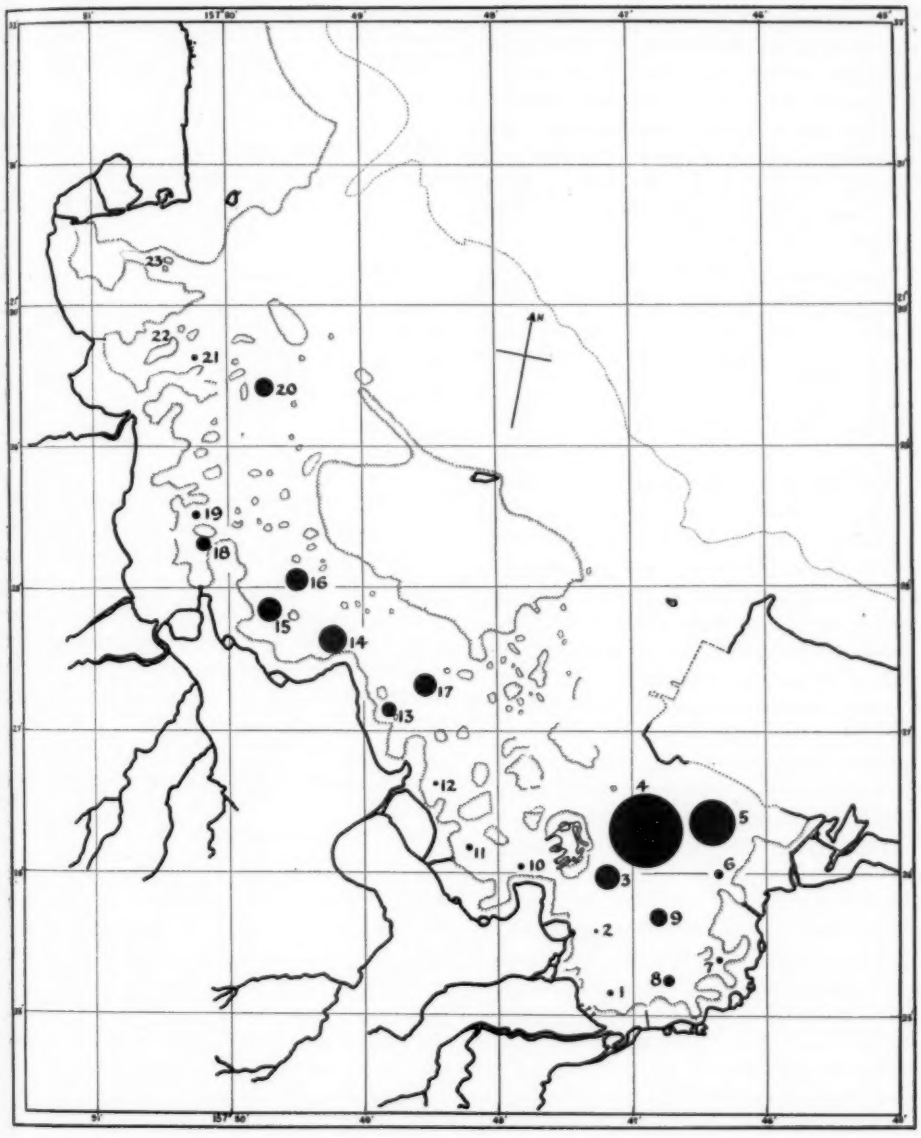

FIG. 4. Map of Kaneohe Bay showing the general distribution of the eggs according to station. The black circles are proportional in area to the number of eggs taken in combined A and B hauls with the 100 cm. net at each station. The distribution is presumed to be continuous between stations, rather than discrete, as shown.

Distribution of Larvae

In considering variation in numbers of larvae with station and survey, data obtained with the 100 cm. net (Table 5) are more informative than those obtained with the smaller nets (Table 6) because of the larger numbers of larvae captured. The results for the 100 cm. net (A plus B hauls), expressed as an average percentage (Table 5), are shown graphically in Figure 5.

The general distribution of larvae according to sector and net is as follows:

SECTOR	LARGE NET		SMALL NETS	
	per cent of total	*mean per cent per station*	*per cent of total*	*mean per cent per station*
Southern	70.52	7.84	76.72	8.52
Middle	27.08	3.38	21.19	2.65
Northern	2.40	0.40	2.08	0.35

The general distribution of larvae is similar to that of the eggs in that they are most abundant in the southern sector, less abundant in the middle sector, and least abundant in the northern sector of the bay. As in the case of eggs, the results are fairly consistent except in Survey 4, when the abundance was greatest in the middle sector.

In the southern sector, the larvae are distributed from station to station in a manner which is conspicuously different from that of the eggs (compare Figs. 4 and 5, or Tables 3 and 5). While not randomly distributed, the larvae are more widely scattered than the eggs. Moreover, they appear to form a peak of abundance at Station 6 or 7 in the southern part of the sector rather than at Station 4 or 5 in the northern part. This peculiar distribution is fairly consistent from survey to survey. Again, the cause is obscure. While larvae are able to swim feebly, they must still be regarded as plankton in the early stages of development and are still largely at the mercy of the currents. A possible explanation will be advanced in a later section which deals with the length composition of the larvae.

In the middle sector of the bay, the larvae again seem to be more widely scattered than the eggs. On the average they were most abundant at Station 14, but this was not consistent from survey to survey. They were most abundant at Station 17 in Survey 1, at Station 11 in Survey 2, at Station 10 in Survey 3, and at Station 14 in Survey 4.

In the northern sector, the larvae were taken in small numbers at Stations 18, 19, and 20 and, on one occasion, at Station 23. It will be recalled that eggs were not taken at Station 23 in any of the four surveys.

Variation with Season

The total numbers of eggs and larvae taken in the 100 cm. net at all stations of each survey are as follows:

STAGE	SURVEY 1 *Sept.*	SURVEY 2 *Dec.*	SURVEY 3 *March*	SURVEY 4 *June*
Eggs	6,757	1,940	10,022	2,432
Larvae	722	267	81	356

From the lack of consistent variation in the numbers of eggs and larvae taken from survey to survey, it is at once apparent that no conclusions can be drawn as to whether spawning is more intensive at one period of the year than at another. Certainly it would seem that spawning takes place throughout the year as found by Delsman (1931) for other species of *Stolephorus* in tropical waters, but information on seasonal variation must await a program of quantitative sampling at closer intervals of time.

MORTALITY OF EGGS

As mentioned previously, the eggs were segregated into three categories at the time of counting—"normal," "damaged," and "agglutinated." On the average, the percentages of eggs falling into the three categories were respectively 75, 20, and 5. However, there was considerable variation from station to station within surveys, and very great variation from survey to survey, particularly in the percentages of normal and damaged eggs. For example, in Survey 3 normal eggs accounted for 40.5 per cent and damaged eggs 58.2 per cent, whereas in Survey 4, normal eggs accounted for 85.5 per cent and damaged eggs 8.8 per cent. The

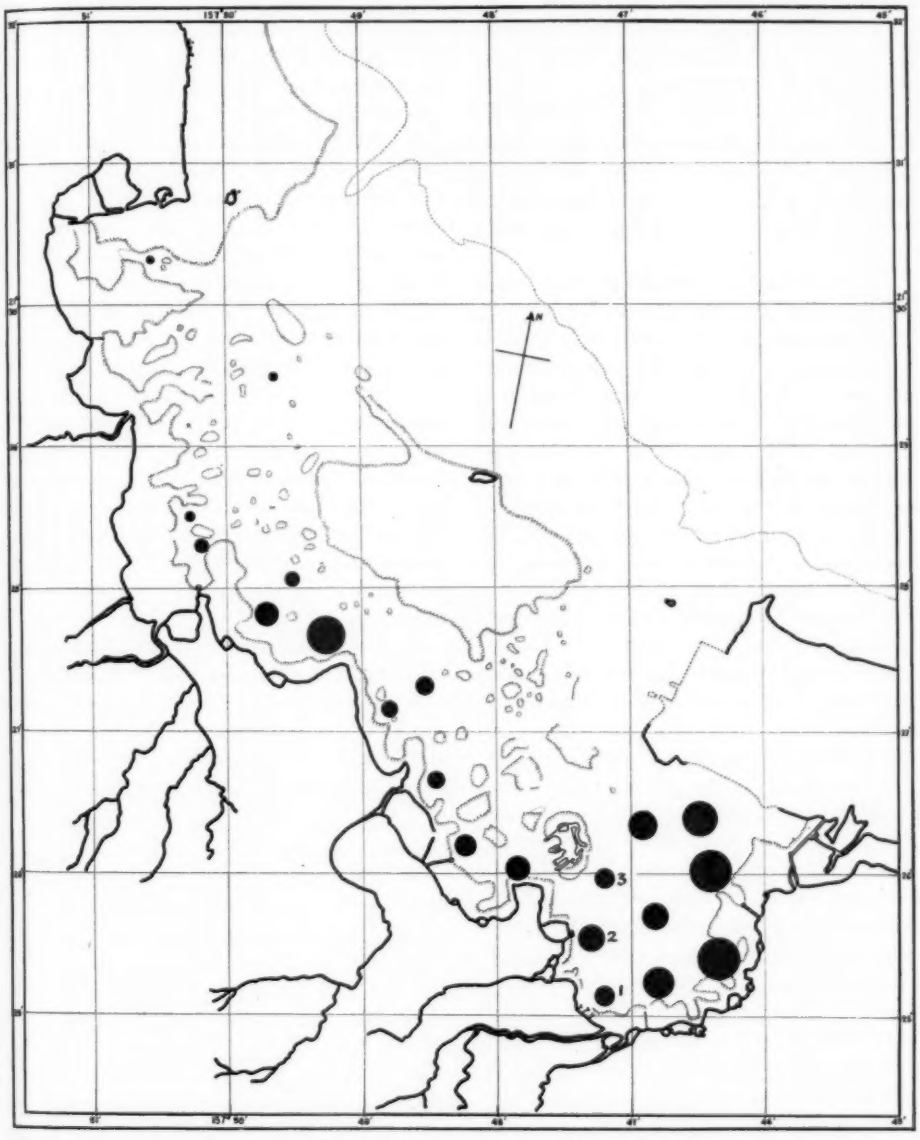

FIG. 5. Map of Kaneohe Bay showing the general distribution of the larvae. The black circles are proportional in area to the number of larvae taken in combined A and B hauls with the 100 cm. net at each station. The distribution is presumed to be continuous between stations, rather than discrete, as shown.

differences between surveys are probably related, in part at least, to differences in speed of tow. The average speed, as determined by readings of the Clarke-Bumpus current meter which was towed behind the boat in these two surveys, was 1.3 times as great in Survey 3 as in Survey 4. A high percentage of damaged eggs was also found in the two interim surveys when, in towing two small nets, the ship travelled faster than in towing a large and a small net.

The percentage of agglutinated eggs, while ranging from 1.3 in Survey 3 to 11.0 in Survey 2, did not seem to vary directly with speed of tow. Although the results are admittedly subject to some degree of error in distinguishing damaged from agglutinated eggs, they suggest that about 5 per cent of the eggs were dead at the time of capture. The only other possibility is that they were damaged on capture at the start of the tow and that decomposition proceeded with sufficient rapidity to reduce them to the agglutinated condition in 10 minutes or less. This seems unlikely.

If the agglutinated eggs are assumed to have been dead at the time of capture, the question arises as to the reason for their death. Some may have been regurgitated by chaetognaths and ctenophores, which were found to feed on the eggs. Others may have died "naturally" because of infertility, lack of vitality, or some other intangible factor. In this regard, D. Yamashita (unpublished) has observed that when normal undamaged eggs are kept in Petri dishes, a small percentage will die for no apparent reason. Determination of the cause and extent of the egg mortality would be of considerable interest and importance in the study of the dynamics of the nehu population.

LENGTH DISTRIBUTION OF LARVAE

The length distribution of larvae taken by both large and small nets is given for each survey in Table 12. It will be observed that the length ranges from 2.5 to 12 mm. Only one individual of larger size (20.5 mm.) was caught. The smallest nehu taken in the seines or night-light nets of the commercial fishermen are about 23 mm. These are post-larval fish which have not yet completely metamorphosed. It is clear, then, that the plankton nets did not sample the larva population completely. It seems reasonable to assume that the larger individuals escaped the net by virtue of their keener vision and greater swimming power, or these coupled with the adoption of the schooling habit.

The average length of the larvae varies significantly from survey to survey; for Surveys 1 to 4, the average lengths are 4.99, 5.73, 5.01, and 3.44 mm., respectively. The differences between surveys are probably related to variation from day to day in the extent of spawning, presuming that several day groups are represented in the length distribution. Although the data for comparing sectors within surveys are scanty, there seems to be a general similarity in the length distributions.

The percentage frequency distribution was calculated for each survey and the resulting four percentages for each length group were averaged, giving the data of the last column of Table 12. The length frequency polygon, shown in Figure 6, is obviously multimodal,

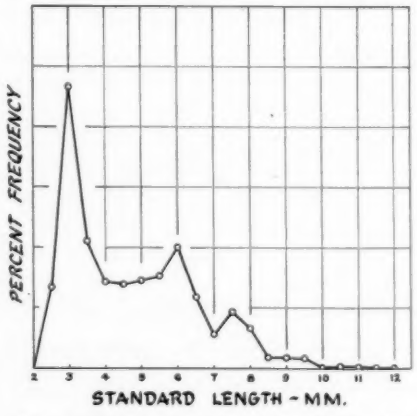

FIG. 6. The per cent frequency distribution of larvae according to length, all data combined.

TABLE 12

FREQUENCY DISTRIBUTION OF LARVAE TAKEN BY ALL NETS ACCORDING TO LENGTH, SURVEY, AND SECTOR (S, SOUTHERN; M, MIDDLE; N, NORTHERN), AND SUMMARY

LENGTH CLASS	SURVEY 1			SURVEY 2			SURVEY 3			SURVEY 4			MEAN PER CENT OF SURVEY TOTAL
	S	M	N	S	M	N	S	M	N	S	M	N	
2.5	27	–	–	–	–	–	8	–	–	28	26	1	7.12
3.0	178	6	1	6	2	–	11	3	–	54	123	4	23.35
3.5	63	–	–	21	4	–	3	2	–	19	43	2	10.27
4.0	57	–	–	10	9	–	–	2	2	11	9	–	7.29
4.5	54	–	–	23	3	4	5	–	–	13	4	–	6.24
5.0	61	1	–	27	5	–	3	1	–	6	2	–	6.81
5.5	73	–	–	20	11	2	3	1	2	3	3	–	7.44
6.0	56	–	–	25	8	2	9	5	–	6	1	–	10.03
6.5	50	–	–	14	12	1	6	–	–	3	1	–	6.33
7.0	41	–	–	5	6	–	1	–	–	3	1	–	2.94
7.5	43	–	–	6	8	2	6	–	–	2	2	–	5.07
8.0	30	1	–	7	6	–	4	–	–	–	1	–	3.56
8.5	9	–	–	2	2	–	1	–	–	–	–	–	0.98
9.0	14	1	–	3	2	–	–	–	–	–	–	–	0.95
9.5	4	1	–	4	1	–	1	–	–	–	–	–	0.95
10.0	3	–	–	–	–	–	–	–	–	–	–	–	0.10
10.5	–	–	–	2	–	–	–	–	–	–	–	–	0.19
11.0	1	–	–	1	–	–	–	–	–	–	1	–	0.19
11.5	1	–	–	–	–	–	–	–	–	–	–	–	0.03
12.0	2	–	–	–	–	–	–	–	–	–	–	–	0.06
–	–	–	–	–	–	–	–	–	–	–	–	–	–
20.5	–	–	–	–	1	–	–	–	–	–	–	–	0.09
Totals*	767	10	1	176	80	11	61	14	3	148	217	7	99.99

* The totals do not agree with those of other tables as some larvae were damaged and could not be measured.

with modes at 3.0, 6.0, 7.5, and possibly 9.0 mm.

In attempting to interpret the biological significance of the modes, it must be remembered that the eggs hatch between 12 midnight and 2 A.M. and that the newly hatched larvae are about 2.0 mm. in length. Since the tows were taken between 9 A.M. and 2 P.M., it seems reasonable to assume that the first mode, at 3.0 mm., includes larvae which are about 9 to 14 hours of age, comprising the 0-day group. Only a few of these, however, had the large yolk sac characteristic of larvae of this age reared in dishes. Some had obviously lost the yolk material when damaged during capture. Others, of 3.0 mm. and larger, appeared to have absorbed the yolk sac almost completely and to have advanced in their general development to a stage 24 hours older, at which the mouth parts are forming. It seems likely, therefore, that the distribution represented by the first mode includes larvae of both the 0-day group (9 to 14 hours) and also the 1-day group (33 to 38 hours).

Once the mouth has formed and the larvae start feeding, more rapid growth might be expected. Thus the modes at 6.0, 7.5, and 9.0 mm. may represent the 2-, 3-, and 4-day groups. This would indicate an absolute growth rate of 1.5 mm. per day. If this rate were maintained, the nehu would become initially vulnerable to the commercial fishery (at a length of about 23 mm.) within about 2 weeks after hatching. If there were a deceleration of growth (which is likely), it may still be assumed that the period between hatching and recruitment is short—a matter of weeks, rather than years as in most temperate zone fishes. The interpretation of the

above results is, of course, tentative. More satisfactory data would be provided by a series of collections on successive days at the same stations.

To investigate the length frequency distribution of the larvae in the southern sector in more detail, the number in each length category for each station was expressed as a percentage of the total number caught in each survey. The four percentages for each length group at each station were then averaged. This method of calculation weights the percentages for each station according to the numbers caught at that station within surveys, but gives equal weight to the numbers caught during each survey. The results are shown in Figure 7.

As might be expected when the data are subdivided, the positions of the modes are somewhat erratic. An extra mode, which may represent the 1-day group, occurs at 4.5 mm. in some cases. In general, the smaller and younger larvae are relatively more abundant at Stations 6, 5, and 4 than elsewhere. Larger and older larvae are particularly abundant at Station 7, which is located behind the reefs at the southeast end of the bay. The results suggest that the newly hatched larvae are at first concentrated in the same area as the eggs, Stations 4 and 5, but that as they become larger and older they disperse from this area, with a large number moving in a clockwise direction through Station 6. The mechanism accounting for the peculiar distribution of larvae in respect to both number and length should be investigated.

Examination of the length distribution of the larvae in the middle sector reveals a somewhat similar situation. In general, the larvae at the centers of egg abundance, Stations 13 to 17, are smaller than those away from the centers, Stations 10 to 12. For example, the average length of the larvae in the former was 3.5 mm. whereas in the latter it was 5.3 mm. Again, this indicates a dispersal of the larvae from the areas of spawning.

In the northern sector only a few larvae were taken. Their average length was 4.6 mm.

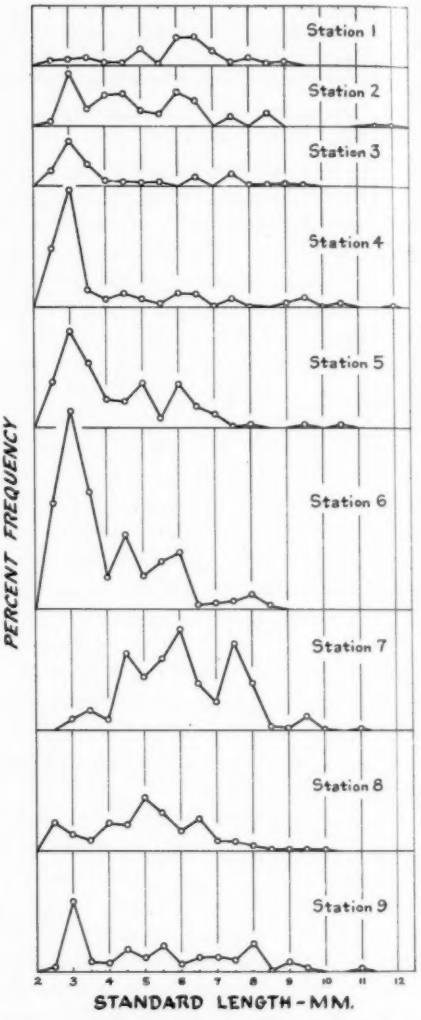

FIG. 7. The per cent frequency distribution of larvae according to length for each station in the southern sector of the bay.

An alternate explanation for the peculiar distribution of larvae in numbers and lengths might be advanced for both the southern and middle sectors. It might be postulated that both eggs and larvae remain close to the scene of spawning, and that the differences

between stations are due primarily to erratic spawning at a station from day to day. This possibility cannot be denied, but such evidence as is presently available lends support to the interpretation given previously.

DISCUSSION

One of the objects of the present investigation was to formulate a sampling program for the estimation of egg and larva production throughout the year. Therefore it is in order to consider the design of such a program in the light of the present results. Its scope, however, must be limited by available funds.

The 100 cm. net is too large to be handled conveniently from a small vessel. The 22 cm. net is too small to give numbers of eggs and, particularly, larvae of sufficient magnitude for precise statistical analysis in a haul of reasonable time duration. Therefore a net of intermediate size, perhaps 50 cm. mouth diameter, is recommended. The net should be constructed of No. 40 grit gauze, and should be equipped with a current or flow meter and a detachable cod end. In design, it might follow that of the Hensen egg net.

Because of the small variability between catches of nets hauled simultaneously and the large variability between individual hauls, it would be more efficient to make several hauls with one net than to make one haul with several nets. For the same amount of work (chiefly involved in sorting plankton) four short hauls at one station, each of 5 minutes' duration, each spaced in regular fashion about the station, and each following a close, circular course, would be more informative than the sampling design followed in the present investigation.

Because of the slight but apparently consistent difference in egg abundance between surface and deep samples, horizontal tows at the surface, rather than either simultaneous surface and deep tows or oblique tows, could be used. However, the vertical distribution of the eggs should be subject to further investigation to determine the nature of the abundance gradient and its variation in time and space.

For a study of variation in abundance of eggs in the southern sector, one station located in the vicinity of Station 4 might suffice, provided it were sampled according to the above plan. Samples should be taken at close intervals of time throughout the year, say two per week. With a program such as this it should be possible to obtain information on both short-term and long-term fluctuations in the abundance of eggs. If the horizontal and vertical gradients of abundance, and their variation, could be established with precision, it should be possible to calculate the absolute abundance of eggs with reasonable accuracy. Interpolation in time and integration of the results would then lead to an estimate of total egg production for the southern sector which, according to this preliminary work, includes about 75 per cent of the total eggs spawned in Kaneohe Bay.

The sampling of eggs in the middle sector of the bay presents greater difficulty because of the lack of consistent variation from station to station with time. At least two, and preferably more than two stations should be included. With limited funds, it would be more efficient to make fewer hauls per station and to include more stations. A possible compromise might be to make two hauls at each of Stations 14 to 17 once a week.

Sampling for eggs in the northern sector might be neglected without any great loss of information, for the eggs occurring there form only about 4 per cent of the total. However, if included, it might be sampled at Station 20, two hauls, once a week.

If carried out as outlined, the above program would produce 936 samples per year. In addition, it would be desirable to check horizontal distribution at all stations and vertical distribution at certain key stations, e.g., Stations 4 and 16, at least at quarterly intervals, thus producing an additional two to three hundred samples. The total, about 1,200 samples, is regarded as the minimal

number necessary for a reasonably accurate estimate of the production of nehu eggs in Kaneohe Bay.

The above program would provide data on variation in the abundance of eggs and, therefore, on variation in the abundance of the sexually mature portion of the fishable stock. Coupled with information on mortality and catch, it could lead to predictions of abundance of the mature population at various levels of fishing effort.

Estimation of larva abundance from plankton hauls is more difficult because of the widespread but non-random distribution of the larvae and their increased ability to escape the net as they become larger. Special stations for the estimation of larva abundance might be established, e.g., Station 7 in the southern sector, but this would greatly increase the number of samples to be collected and sorted. It might be possible to measure the abundance of larvae more accurately and with less effort by another method of collection—quantitative night-light traps. This possibility is now under investigation.

The reasons for the peculiar distribution of eggs and larvae in Kaneohe Bay are unknown, although presumably the distribution is related to the prevailing current pattern. A hydrographic study of the current system in all sectors of the bay at various times of year and under various weather and tide conditions is highly desirable.

The investigation was confined to the waters within Kaneohe Bay. There is the possibility that nehu eggs may also occur in coastal and offshore waters outside the bay. The presence of anchovy eggs in offshore waters has been reported for other species, e.g., the Australian anchovy, *Engraulis australis*, investigated by Blackburn (1941), the California or Northern anchovy, *Engraulis mordax*, investigated by Marr and Ahlstrom (1948), and several species of *Engraulis* occurring along the coast of Java and Sumatra, investigated by Delsman (1929). Furthermore, the eggs of several species of *Stolephorus* were also found offshore by Delsman (1931) in the last-named tropical locality. On the other hand, our local anchovy, the nehu, does not characteristically occur in the open ocean. As pointed out by Tester and Hiatt (in press), it appears to be confined to the bays and inlets where the water is somewhat more turbid and less saline than that of the open sea. As far as can be determined, nehu eggs have not yet been recovered from offshore waters adjacent to Hawaii by other agencies in the Territory who have made plankton hauls for pelagic fish eggs. Although it seems likely that nehu eggs do not occur extensively in offshore waters, the possibility that they are carried to or spawned in the open sea should be investigated.

The early life history of the nehu appears to be similar to that of the tropical anchovies studied by Delsman (1929 and 1931). In both, spawning takes place throughout the year, spawning occurs at night, there is a rapid embryonic development with an incubation period of 24 hours or less, and there is rapid growth during the larval stages. Two general features—continuous spawning and rapid development—present new problems in the field of fishery management.

SUMMARY

An investigation of the distribution of anchovy or "nehu" eggs and larvae in Kaneohe Bay, Oahu, Territory of Hawaii, was conducted during 1948 and 1949. It was exploratory in nature, and was designed partly to determine an efficient sampling program and partly to obtain information on the horizontal, vertical, and seasonal distribution of the eggs and larvae.

In each of four surveys (September, December, March, and June) 23 stations were sampled. Of these, nine were in the southern sector, eight in the middle sector, and six in the northern sector of the bay.

Three nets with respective mouth diameters of 100, 22, and 12.3 cm. were used. The large net and one of the two small nets were towed

simultaneously at each station, first in one direction and then in the opposite direction, just below the surface. In addition, two interim surveys were undertaken to investigate the horizontal and vertical distribution of the eggs and larvae at one station in more detail.

Nehu eggs and larvae were identified and nehu larvae were measured. The bluntly ovoid eggs, typical of several species of anchovy, were readily recognized. Some were obviously damaged during tows; others, amounting to about 5 per cent, were apparently dead at the time of capture.

A study of variability of the data revealed heterogeneity between stations, haul order (A and B), and nets, together with a significant interaction between stations and haul order. From the same analysis, it was found that the small nets were relatively more efficient than the large net, but that this could be attributed in part to loss of plankton from the latter because of rips which developed during one survey, and perhaps also to poor technique in handling the catch in the others.

Two interim surveys were undertaken at one station to determine the reason for the difference between A and B hauls and also to study the variation with depth. Both the heterogeneity in haul order and the interaction between stations and haul order could be explained on the basis of non-random distribution of the eggs. Apparently there was a focus of abundance of eggs, and gradients of decreasing abundance extending outward in all directions. Slight variation in the course followed by the vessel in making the hauls would produce large variation in catch because the egg concentration would be transversed at different distances from the focus.

The eggs were slightly more abundant toward the surface than at a depth. A gradient of decreasing abundance with depth was postulated.

Both eggs and larvae were present in all four surveys, showing that spawning takes place throughout all seasons of the year. Whether it is generally more intensive during the summer than during the winter remains to be determined.

Both eggs and larvae were generally most abundant in the southern sector of the bay, less abundant in the middle sector, and least abundant in the northern sector.

Neither eggs nor larvae were randomly distributed within sectors. In the southern sector there was evidently a focus of abundance of eggs in the northerly part. This peculiar distribution is probably related to the current pattern, with the eggs being held in an eddy. There are indications that the larvae are distributed in a similar manner to the eggs when first hatched, but that they gradually disperse as they become larger and older, and tend to become concentrated in the southern part of the bay. In the middle and northern sectors there were several foci of abundance of eggs, their presence and location probably depending on the time and place of spawning and the prevailing current system.

Several modes were evident in the length frequency distribution of the larvae. These were tentatively interpreted as day groups, and indicated an absolute growth rate of about 1.5 mm. per day during the initial growth period. The results suggest a remarkably short period between hatching and recruitment to the fishery, and a rapid overturn in the population, a situation which is probably typical of anchovy populations in tropical waters.

Based on the results of this preliminary work, a sampling program designed to measure total annual egg production in Kaneohe Bay was suggested. Details of gear, stations, and hauls were briefly discussed. It was recommended that, if possible, some other method of collection be used to determine the abundance of larvae.

The investigation was confined to the waters of Kaneohe Bay. Although it is considered unlikely that nehu eggs occur in large quantity in waters outside the bay, the possibility should be investigated in the future.

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Food and Feeding Habits of the Nehu, *Stolephorus purpureus* Fowler[1]

ROBERT W. HIATT[2]

INTRODUCTION

THE NEHU, *Stolephorus purpureus* Fowler,[3] comprises about 95 per cent of all the baitfish used by tuna fishermen in Hawaii. Despite the fact that this species is widely used for livebait, the baiting grounds are highly restricted in extent throughout the main Hawaiian Islands and differ markedly in their productivity. The most important baiting areas have been mapped in a recent paper which deals with racial segregation of nehu among the main Hawaiian Islands (Tester and Hiatt, in press). It suffices here to state that Kaneohe Bay, located on the northeast side of Oahu, is the leading baiting ground in Hawaii, producing, according to statistics compiled by the Territorial Division of Fish and Game, approximately 60 per cent of the total commercial catch.

Ecologically, nehu appear to be restricted to sheltered coastal waters which are somewhat less saline than oceanic water, although the adults live without noticeable deleterious effect in baitwells of tuna boats at sea and, on occasion, have been observed outside the reefs in waters completely oceanic in composition. Inshore areas suitable for nehu are scarce around the Hawaiian Islands, and in a few of these baiting grounds the population density is often great. The importance of this species to the tuna industry, coupled with the fact that the supply available in these few areas is somewhat precarious, as evidenced by the recent decline in the nehu population in Hilo Bay, has indicated the need for an intensive study of its biology and population dynamics.

Only two brief references to the food and feeding habits of this species exist (Hiatt, 1947*a*: 241; 1947*b*: 271), but, since these do not treat this subject in sufficient detail, the present study on the food and feeding habits of adult nehu was undertaken. Fish from five different baiting areas are analyzed to ascertain if differences and similarities in food habits may be related to variations in their size and vigor. Where adequate data are available, a comparison is made between the food organisms available and the food organisms eaten throughout the year.

METHODS

Collections of fish were made both through the cooperation of commercial fishermen and by the use of the fishery research vessels of the Hawaii Marine Laboratory and the Territorial Division of Fish and Game. With the exception of the fish taken in Ala Wai Canal and in Pearl Harbor, most fish were caught by night-baiting methods, as described by June (1951). The fish taken in the two areas mentioned were seined during early morning day-baiting operations (June, *op.cit.*).

Fish samples were obtained from Ala Wai Canal and from Kaneohe Bay during all seasons of the year. Although collections were sparse in Pearl Harbor, Honolulu Harbor, and Hilo Bay, these data are included because the consistent year-round supply of the important food organisms in a particular area in Hawaiian waters (see Tables 3 and 6) and the consistency of the organisms eaten month to

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[3] The confused generic designation of this species within the family Engraulidae has been discussed by Gosline (1951).

month in a given area (see Tables 4 and 7) result in the diet for any period agreeing rather closely with the average daily diet throughout the year. Thus, an adequate sample for a single month, while appearing scanty for year-round appraisal, has much more value in this area than it would where extensive seasonal variation is the rule. Table 1 indicates the number of fish examined each month for each locality.

The stomach of each fish was removed and opened, and the contents were washed into a Syracuse watch glass. The organisms present were identified to the most exclusive taxonomic category practicable, then counted and recorded.

For each area these calculations were made: the average percentage by number of the complete stomach contents which each type of organism constituted; the average number of organisms in the stomachs; and the percentage of stomachs containing the organism. Emphasis is laid upon percentages by number rather than upon volume. While this method is not altogether satisfactory because the size of the different food elements varies considerably, it provides the best general idea of the relative importance of the various components because of the selective method of feeding. To circumvent misconceptions arising from such treatment of data of this sort Hardy (1924: 19), dealing with food analyses of herring, gave increased values to larger organisms to compensate for larger size. This practice has not been followed in this paper, so it must be borne in mind that ghost shrimps, hyperiid amphipods, crab megalopa, and shrimps are considerably larger than copepods and barnacle larvae. Since data are presented by areas, and since the size range among food organisms taken in each area is not as great as in the food of some other species of fish, the percentages would not be greatly altered if compensation were made for variation in size of organisms. The only important difference in sizes occurs where copepod eggs are present in considerable quantity. The data for Kaneohe Bay and Pearl Harbor should be considered with this difference in mind because adult copepods are many times larger than their eggs.

In tabulating the data, the collections were grouped according to locality, and the general mean for an area was obtained by averaging the totals for the year. The results of the food analyses are summarized for Kaneohe Bay in Table 2, for Ala Wai Canal in Table 5, for Honolulu Harbor in Table 8, for Pearl Harbor in Table 9, and for Hilo Bay in Table 10. The relative importance (percentage by number) of the most important food organisms consumed in each area is diagrammed in Figure 1 so that food habits in the five areas may be compared. To assess objectively the extent to which nehu depend upon the various components of the plankton, an analysis was made of the gross aspects of the month to month fluctuation in plankton organisms in Kaneohe Bay and Ala Wai Canal (Tables 3 and 6). Possible seasonal change in food habits of nehu in these two baiting areas was determined by tabulating the food organisms present in the stomachs month by month (Tables 4 and 7).

TABLE 1

THE NUMBER OF NEHU EXAMINED EACH MONTH FOR EACH LOCALITY

LOCALITY	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
Kaneohe Bay.....	4	8	10	–	8	–	5	12	19	6	8	–	80
Ala Wai Canal.....	–	1	3	–	56	–	17	–	–	4	–	–	81
Pearl Harbor.....	2	–	–	2	–	–	–	–	–	17	–	–	21
Honolulu Harbor..	–	–	–	–	–	–	20	–	–	–	–	–	20
Hilo Bay.....	–	–	–	–	–	–	–	20	–	–	–	–	20
													222

TABLE 2

FOOD OF NEHU (*Stolephorus purpureus*) IN KANEOHE BAY, OAHU, BASED ON AN ANALYSIS OF 80 STOMACHS

ORGANISM	PERCENTAGE FREQUENCY OF OCCURRENCE AMONG FISH EXAMINED	AVERAGE NUMBER TAKEN PER FISH CONTAINING THE ITEM	PERCENTAGE COMPOSITION OF FOOD ITEMS BASED ON TOTAL NUMBER OF ORGANISMS FOUND IN THE STOMACHS
Copepods			
adults	79	16	35
eggs	30	23	19
Shrimps			
adults	6	1	TRACE
mysis	29	19	15
zoeae	5	11	1
Barnacle larvae			
nauplii	25	20	13
cypris	25	7	5
Crab zoeae	25	12	8
Amphipods (Hyperiidae)	11	7	2
Ghost shrimps (*Leucifer faxonii*)	11	2	1
Isopods	4	2	TRACE
Gastropod veliger larvae	1	1	TRACE
Ostracods	1	2	TRACE
Stomatopod larvae	1	8	TRACE
Fish larvae	1	3	TRACE
Diatoms	3	4	TRACE

Acknowledgments: Personnel of the Hawaiian Tuna Packers Corporation and commercial fishermen belonging to the Tuna Boat Owners Association were very helpful in securing samples of nehu for this study. Fishery biologists employed by the Territorial Division of Fish and Game and by the University of Hawaii have been most cooperative in securing specimens for analysis. To all these individuals the writer extends his appreciation for their interest and assistance.

ANALYSIS OF FOOD AND FEEDING HABITS

Food organisms eaten: Reference to Figure 1 will show certain local differences in the kinds and proportions of food items taken by nehu. Copepods—either adults, nauplii, or eggs—predominate in nehu taken in Kaneohe Bay, Pearl Harbor, and Hilo Bay, with the latter two areas much alike in the items and proportions thereof taken. In the remaining two areas, Ala Wai Canal and Honolulu Harbor, copepods are of little or no importance to nehu as food, the chief items eaten being ghost shrimps (*Leucifer faxonii*) and crab megalopa. In most cases the largest fish in a sample contained the greatest volume of food, and the stomachs of the characteristically large nehu from Ala Wai Canal and Honolulu Harbor were usually greatly distended, as compared with the rarely distended stomachs of smaller fish distinctive of other areas. The monthly distribution of food organisms taken in Kaneohe Bay (Table 4) and in Ala Wai Canal (Table 7) shows very little change during any period of the year in regard to the more important dietary items.

A comparison of the food habits of the nehu with other anchovies is not very satisfactory because so few comparable studies have been made. Similar components of the zooplankton are taken by the Mediterranean anchovy, *Engraulis encrasicholus* (Miranda y Rivera, 1930), and by a Japanese engraulid, *Coilia mystus* (Suyehiro, 1942), which has an alimentary canal almost identical with that of the nehu. However, certain fundamental differences in the diet of other anchovies are ap-

TABLE 3

MONTHLY DISTRIBUTION OF THE DOMINANT PLANKTON COMPONENTS IN KANEOHE BAY, OAHU, BASED ON ROUTINE BI-WEEKLY HAULS IN AREAS OCCUPIED BY NEHU. THE SYMBOL xxx DENOTES GREAT ABUNDANCE, xx DENOTES COMMON OCCURRENCE, AND x DENOTES UNCOMMON OR RARE OCCURRENCE

ORGANISM	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Chaetognatha (*Sagitta*)	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Copepods (nauplii and adults)	xxx	xx	xxx	xx	xx	xxx	xx	xx	xxx	xx	xxx	xxx
Ctenophora	xxx	xxx	xxx	xxx	xx	xxx	xxx	xxx	xx	x	xxx	xxx
Shrimp larvae (mysis)	xx	xx	xx	x	x	xx	x	x	xx	x	xx	x
Shrimp larvae (zoeae)	xx	x	xxx	x	x	xxx	x	xx	xx	x	xx	xx
Crab larvae (zoeae)	xx	xxx	xxx	xxx	xx	xxx	x	xx	xxx	xxx	x	xxx
Ghost shrimps (*Leucifer faxonii*)	–	–	xx	x	xx	xx	xx	x	x	–	x	x
Barnacle larvae (nauplii)	x	xx	x	–	–	–	–	x	x	xx	xxx	xxx
Barnacle larvae (cypris)	–	x	–	–	–	–	–	–	–	–	–	–
Amphipoda (Hyperiidae)	–	x	x	x	x	x	x	xx	xx	–	–	–
Tunicata (Larvacea)	x	x	x	x	x	x	x	xx	x	xx	x	x
Gastropod and pelecypod larvae	x	x	x	x	x	x	x	–	–	–	x	–
Ostracoda	–	–	x	x	–	x	x	x	–	–	x	x
Stomatopoda larvae	–	–	x	–	–	xx	–	x	x	–	x	x
Isopods	x	–	–	–	–	–	–	–	x	–	–	–
Annelida larvae	–	x	–	x	x	–	–	–	–	–	–	–
Medusae	–	–	x	x	–	–	–	–	–	–	–	–

parent. Although too few fish were examined for reliable results, Allen (1921: 543) reported the stomachs of the West Coast anchovy, *Engraulis mordax*, to contain only diatoms and dinoflagellates, and Suyehiro (1942: 54) showed the Japanese anchovy, *Engraulis japonicus*, to be exclusively a feeder on phytoplankton. Nishikawa (1901), studying this same anchovy, found that the young fed chiefly on copepods and did not specialize on phytoplankton until adulthood was attained. Correspondingly, the intestine of *E. japonicus* is much longer than that of the nehu, and it is suggestive of herbivorous rather than carnivorous habits. The lack of phytoplankton in the diet of Hawaiian anchovies might be attributed to the fact that diatoms and dinoflagellates are very sparse in the Hawaiian area.

TABLE 4

MONTHLY CHARACTERISTICS OF THE FOOD HABITS OF NEHU IN KANEOHE BAY. THE SYMBOL x DENOTES OCCURRENCE IN STOMACH CONTENTS

ORGANISM	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Copepods (nauplii and adults)	x	x	x	–	x	–	–	x	x	x	x	–
Barnacle larvae (nauplii)	x	x	x	–	x	–	–	x	x	–	–	–
Barnacle larvae (cypris)	x	x	x	–	x	–	–	–	–	–	–	–
Crab zoeae	–	–	x	–	–	–	x	x	x	x	–	–
Shrimps	–	–	–	–	x	–	x	–	–	–	–	–
Shrimp larvae (zoeae)	–	–	–	–	–	–	–	–	–	x	–	–
Shrimp larvae (mysis)	x	–	–	–	x	–	–	x	x	x	–	–
Ghost shrimp (*Leucifer faxonii*)	–	–	–	–	–	–	–	x	x	–	–	–
Amphipoda (Hyperiidae)	–	–	–	–	–	–	–	x	x	–	–	–
Isopods	–	–	–	–	–	–	–	x	x	–	–	–
Stomatopoda larvae	–	–	–	–	–	–	–	x	–	–	–	–
Fish larvae	–	–	–	–	–	–	–	–	x	–	–	–
Ostracoda	–	–	–	–	–	–	–	–	x	–	–	–
Veliger larvae	–	–	–	–	–	–	–	–	–	x	–	–

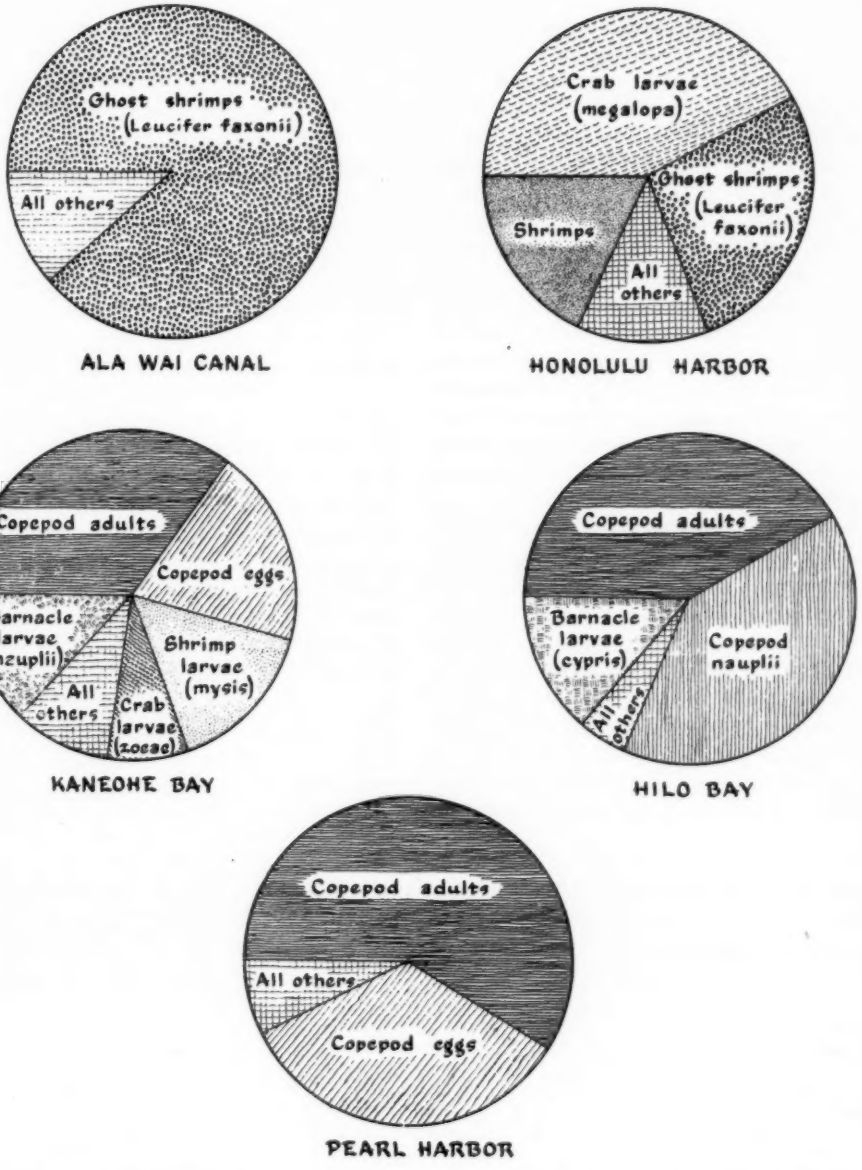

FIG. 1. Summary of the food habits of nehu from the five baiting areas investigated in this study.

The food and feeding habits of nehu and other engraulids are quite similar to those of the closely related clupeids. Herring in the North Pacific (Kuragami, 1930; Wailes, 1935), in the North Atlantic (Moore, 1898; Weber and Wilson, 1920; Bigelow and Welsh, 1925), and in European waters (Widegren, 1876; Lebour, 1924; Hardy, 1924; Jespersen, 1928; Savage, 1931, 1937; Lucas, 1936) all consume about the same components of the zooplankton as do nehu. Sardines, both in Japanese and California waters (Suyehiro, 1942), consume a good deal of phytoplankton as well as zooplankton, with the composition of the stomach contents roughly proportional to the composition of the plankton. Thus, the food habits of nehu resemble those of herring more closely than those of sardines, yet there are other anchovies which feed more like sardines than like herring.

Selective feeding: The question of selective feeding may best be answered by considering the feeding habits in each area for which data have been collected on available food organisms. A comparison of Tables 2 and 3 for Kaneohe Bay indicates that (1) nehu do not accept planktonic forms indiscriminately, because few plankters other than crustaceans are eaten, although the dominant components of the plankton are chaetognaths and ctenophores; and (2) nehu do take the dominant crustacean types, about in proportion to their occurrence; i.e., copepods, mysis larvae of shrimps, zoeal larvae of crabs, and nauplii of barnacles, which are the most abundant forms found in the stomach contents, also predominate in the available plankton.

A similar analysis was made in Ala Wai Canal (Tables 5 and 6) with quite different results. Here ghost shrimps predominate by far in the stomach contents, and nine out of every ten fish contained them. By comparing the data in the tables indicated above, it is clear that in this locality (1) nehu do discriminate among the total composition of the plankton, e.g., they did not contain any medusae, isopods, chaetognaths, or polychaetes, and (2) nehu do not accept the crustaceans present in the plankton in the order of their abundance. From the standpoint of organisms available, crab zoeae and barnacle nauplii exceeded by far the number of ghost shrimps present, yet the percentage composition of the food items consumed, based on the total number of organisms found in the stomachs, shows that ghost shrimps were unquestionably preferred. The smaller, but more abundant crustaceans such as crab zoeae, barnacle nauplii, copepods, and the zoeal and mysis larvae of shrimps were almost neglected, and in no case did as much as 10 per cent of the fish examined take them,

TABLE 5

FOOD OF NEHU (*Stolephorus purpureus*) IN ALA WAI CANAL, HONOLULU, BASED ON AN ANALYSIS OF 81 STOMACHS

ORGANISM	PERCENTAGE FREQUENCY OF OCCURRENCE AMONG FISH EXAMINED	AVERAGE NUMBER TAKEN PER FISH CONTAINING THE ITEM	PERCENTAGE COMPOSITION OF FOOD ITEMS BASED ON TOTAL NUMBER OF ORGANISMS FOUND IN THE STOMACHS
Ghost shrimps (*Leucifer faxonii*)	91	27	90
Shrimps			
mysis stage	5	15	3
zoeae	5	9	2
Barnacles			
cypris stage	10	9	3
nauplii	1	3	TRACE
Copepods			
adults	9	4	1
eggs	1	3	TRACE
Crab zoeae	6	1	TRACE
Filamentous algae	1	1	TRACE

TABLE 6

MONTHLY DISTRIBUTION OF THE DOMINANT PLANKTON COMPONENTS IN ALA WAI CANAL, HONOLULU, BASED ON ROUTINE BI-WEEKLY HAULS IN AREAS OCCUPIED BY NEHU. THE SYMBOL xxx DENOTES GREAT ABUNDANCE, xx DENOTES COMMON OCCURRENCE, AND x DENOTES UNCOMMON OR RARE OCCURRENCE

ORGANISM	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Ghost shrimps (*Leucifer faxonii*)	xxx	xxx	xxx	xxx	xx	xx	xx	x	xx	xx	xx	xx
Crab zoeae	xx	xx	xx	xxx	xx	xxx	xxx	xx	xxx	xxx	xxx	xxx
Barnacle larvae (nauplii)	xx	x	xx	xxx	xx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Copepods	xxx	xxx	xx	xx	x	xxx	xx	x	xxx	x	x	xxx
Medusae	xxx	x	x	x	xxx	xxx	xx	x	x	xxx	xx	xxx
Shrimp larvae (mysis)	x	x	x	x	x	xx	x	x	xx	x	xx	xxx
Shrimp larvae (zoeae)	xx	x	xx	x	x	xx	x	x	x	xx	x	xxx
Isopoda	x	–	xxx	xxx	xx	x	–	–	x	–	x	x
Chaetognatha (*Sagitta*)	–	xx	xx	–	–	x	x	–	x	–	–	x
Polychaeta	–	–	x	x	x	x	x	–	–	–	–	–

notwithstanding their continued presence in abundance throughout the year. Of importance in understanding the differential selection of food in Ala Wai Canal is the fact that ghost shrimps are exceedingly abundant there, the population density per unit volume being many times greater than that in Kaneohe Bay. Somewhat anomalous is the apparent disregard by nehu in Kaneohe Bay of ghost shrimps and hyperiid amphipods which are available during most of the year, although in much smaller quantities than in Ala Wai Canal.

In regard to the selection of food organisms, the food habits of nehu in Honolulu Harbor (Table 8) are quite similar to those in Ala Wai Canal. Nehu here depend chiefly on the larger crustacean elements in the plankton, with crab megalopa, ghost shrimps, and small palaemonid shrimps comprising the bulk of the food. Small plankters were taken incident to larger items only by a few fish, and these plankters constituted less than 10 per cent by number of all the organisms taken. The rather small nehu from Pearl Harbor consumed mostly copepods and a smaller quantity of crab zoeae (Table 9). An analysis of the plankton (unpublished MS.) indicates that copepods comprise the most important component, with crab and shrimp zoeae ranking second and third, respectively. It is apparent that nehu in this area exercise little or no selection among the plankters except to ignore organisms other than crustaceans. No quantitative data are available for plankton in Hilo Bay, but the results of several tows made incident to a survey of pollution in the bay indicate a very low population density, and the organisms present are comparatively very small in size. No ghost shrimps, amphipods, larval shrimps, or crab megalopa were found. The minute food items found in the stomachs of fish from this area were present in about the same proportion as they occurred in the plankton. The above analyses indicate that the nehu is definitely a feeder on the

TABLE 7

MONTHLY CHARACTERISTICS OF THE FOOD HABITS OF NEHU IN ALA WAI CANAL. THE SYMBOL x DENOTES OCCURRENCES IN STOMACH CONTENTS

ORGANISM	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
Ghost shrimps (*Leucifer faxonii*)	–	–	x	–	x	–	x	–	–	–	–	–
Copepods	–	x	–	–	x	–	–	–	–	x	–	–
Barnacle larvae (cypris)	–	x	x	–	–	–	–	–	–	x	–	–
Crab zoeae	–	–	x	–	x	–	–	–	–	–	–	–
Shrimp zoeae	–	–	–	–	x	–	–	–	–	x	–	–

TABLE 8

FOOD OF NEHU (*Stolephorus purpureus*) IN HONOLULU HARBOR, OAHU, BASED ON AN ANALYSIS OF 21 STOMACHS

ORGANISM	PERCENTAGE FREQUENCY OF OCCURRENCE AMONG FISH EXAMINED	AVERAGE NUMBER TAKEN PER FISH CONTAINING THE ITEM	PERCENTAGE COMPOSITION OF FOOD ITEMS BASED ON TOTAL NUMBER OF ORGANISMS FOUND IN THE STOMACHS
Crab larvae			
megalopa	100	20	42
zoeae	25	10	5
Ghost shrimps (*Leucifer faxonii*)	70	18	27
Shrimps			
adults	40	21	18
mysis	15	10	3
Copepods	40	6	5
Barnacle larvae (cypris)	10	2	TRACE

crustacean components of the zooplankton, and that selection of crustacean types is apparent in some areas and lacking in others.

From the standpoint of selection of food items, nehu resemble herring more nearly than they do sardines. While opinion is divided on the question of selection of plankters by sardines, most investigators agree that there is little or no selection exercised (Kishinouye, 1907; Lewis, 1929; Suyehiro, 1942), but Parr (1930) believes that phytoplankton is ingested only incidentally while sardines pursue zooplankton. Overwhelming evidence for selection in the feeding of herring has been advanced by Moore (1898), Hardy (1924), Bigelow and Welsh (1925), Bigelow (1926), Jespersen (1928), Savage (1931, 1937), Lucas (1936), Wailes (1935), and Johnson (1940). It is generally agreed that herring feed by active pursuit on sight and that adult fish ignore the smallest forms of copepods even though they may be the most abundant in the plankton. The plankters selected showed nice agreement between the occurrence in the herring food and in plankton samples. These findings are comparable to those discovered for nehu. Lebour (1920: 262) aptly sums up this subject for herring and other small plankton feeding fishes, except possibly the sardine, by stating: ". . . usually each species of fish selects its own favourite food, to which it keeps, indiscriminate feeding seldom or never taking place. . . ."

Ingestion: To learn how nehu ingest their food, a small school was confined in a display tank into which living ghost shrimps were then placed. The fish swam quickly to the shrimps and ate them without slackening their swimming speed. When a nehu sighted a ghost shrimp to one side it would make a quick sideways movement in turning to reach the shrimp. In doing this the whole body partly turns over producing a flash from the silvery side when viewed from above. This sideways movement and silvery flash are one of the characteristic features of a school of nehu, and serve to distinguish nehu from another important baitfish, the iao (*Pranesus insularum*), during both day and night baiting operations. Captive herring have been observed to behave similarly (Johnson, 1940: 392).

Relation of size of fish to size of food: Length-frequency plots of nehu in the commercial catch for the various baiting areas clearly show characteristic differences in the average size of fish (unpublished data). Certain of the areas involved in this study (Ala Wai Canal and Honolulu Harbor) can always be depended upon to provide larger fish than the other areas mentioned. The nehu in Kaneohe Bay and in Pearl Harbor are characteristically small in size, with those in Hilo Bay still smaller. Obviously, factors other than food supply may operate to regulate the average size composition of a fish population, such as (1) differences in fishing intensity from one

area to the next, or (2) hereditary differences in growth rate. Unfortunately, the effect of fishing intensity on the population characteristics of nehu is unknown. Furthermore, while racial segregation, as evidenced by an analysis of meristic features, has been shown between certain areas, it has not been shown for others (Tester and Hiatt, in press), so no conclusions may be drawn concerning hereditary differences in growth rate from one area to the next. We do know that (1) the average size of fish in the commercial catch differs between areas but is rather consistent within an area, (2) the composition of the plankton differs between areas but is rather consistent within an area, and (3) large nehu exercise some selection and take mostly the larger forms among the available crustacean plankters, while small nehu seem to take the smaller crustacean components in about the same proportion as they occur in the plankton. From these data certain implications may be made concerning the relation of the size of fish to the size of food.

It was noted previously that a predilection for certain abundant, large crustacean plankters and a virtual disregard for even more abundant but smaller crustacean plankters was apparent in nehu living in Ala Wai Canal and Honolulu Harbor. Both these areas produce nehu of comparatively large size. The medium-sized nehu of Kaneohe Bay and Pearl Harbor and the very small nehu of Hilo Bay do not exercise appreciable selection among the crustacean elements in the plankton. In Kaneohe Bay and in Pearl Harbor large crustacean plankters are sparse in contrast with similar forms in Ala Wai Canal and Honolulu Harbor, while in Hilo Bay large crustaceans are absent and smaller ones are sparse. Thus there appears to be a positive relationship between the size of fish and the size of crustacean plankters available, and a relationship between the size of fish and the size of crustacean plankters consumed. With regard to the former, it appears possible that nehu may not exceed a certain size unless a sufficient quantity of food of the proper type and size is available. Underlying reasons for such a hypothesis involve nutritional demands per unit of time on the part of the fish and the proportional protein content of small versus larger crustaceans, subjects on which no data are available. With food organisms ranging from minute to large sizes, available in adequate amounts, it is possible that the growth rate of nehu is sufficiently rapid to provide characteristically larger fish to the commercial catch in certain areas. Where the food supply lacks organisms beyond a certain size, growth may slacken appreciably as the fish becomes larger and nehu of characteristically smaller average size might result in other areas.

TABLE 9

FOOD OF NEHU (*Stolephorus purpureus*) IN ULUMOKU POND, PEARL HARBOR, OAHU, BASED ON AN ANALYSIS OF 21 STOMACHS

ORGANISM	PERCENTAGE FREQUENCY OF OCCURRENCE AMONG FISH EXAMINED	AVERAGE NUMBER TAKEN PER FISH CONTAINING THE ITEM	PERCENTAGE COMPOSITION OF FOOD ITEMS BASED ON TOTAL NUMBER OF ORGANISMS FOUND IN THE STOMACHS
Copepods (*Acrocalanus inermis*)			
adults	90	83	60
eggs	90	47	34
Crab zoeae	86	6	4
Shrimps (*Leander debilis*)			
zoeae	10	1	TRACE
megalopa	10	21	2
Barnacle larvae (cypris)	48	1	TRACE
Ghost shrimps (*Leucifer faxonii*)	5	1	TRACE

TABLE 10

FOOD OF NEHU (*Stolephorus purpureus*) IN HILO BAY, HAWAII, BASED ON AN ANALYSIS OF 20 STOMACHS

ORGANISM	PERCENTAGE FREQUENCY OF OCCURRENCE AMONG FISH EXAMINED	AVERAGE NUMBER TAKEN PER FISH CONTAINING THE ITEM	PERCENTAGE COMPOSITION OF FOOD ITEMS BASED ON TOTAL NUMBER OF ORGANISMS FOUND IN THE STOMACHS
Copepods			
adults	80	9	41
nauplii	55	13	40
Barnacle larvae			
cypris	80	3	14
nauplii	10	7	4
Nehu scales	30	–	–
Crab zoeae	5	4	1

With regard to the relationship between the size of fish and the size of organisms consumed, it is probably a function of the abundance of organisms of various sizes combined with the physical ability of the fish to catch and ingest them. Ghost shrimps are not present in the stomachs of small nehu, even in areas where these crustaceans are abundant. Large fish in areas where large crustaceans are abundant in the plankton naturally select them over small crustaceans because they can ingest organisms of larger size and their nutritional requirements would probably be fulfilled in less time and with less energy expended. Fish in areas lacking larger crustacean plankters have no choice in the matter.

Relation of food to vigor: Fishermen are cognizant of the differences in the characteristic vigor of nehu caught in the various baiting areas. The small fish from Hilo Bay and Kaneohe Bay seem less able to withstand the handling and confinement required in catching, transferring, and transporting them to the tuna fishing areas than are the larger and more vigorous fish taken in Ala Wai Canal and Honolulu Harbor. While we have no data which would compare vigor in small and large fish in the same baiting area, it is possible that vigor is directly related to the size of the fish. Small herring, for example, are more fragile and less hardy than large herring because they lose their scales more readily. Some evidence that hardiness in nehu may resemble that for herring was found by examining the stomach contents of nehu caught in Hilo Bay. Approximately one-third of the fish stomachs contained nehu scales. The shiny scales were sighted and ingested as they were shed into the water. The taking of scales would be only of academic interest if it were not for the fact that Hilo Bay nehu are very small, exceedingly fragile and weak, and difficult to maintain alive in bait wells. If these small nehu lose their scales more readily than do larger nehu, as is true for herring, the excessive fragility may be associated with the small size. Although we have insufficient evidence at present, further study on the relation of vigor to size and of size to food available may indicate the principles underlying the apparent differences in size and vigor of nehu in the various baiting grounds.

SUMMARY

Investigations into the food and feeding habits of the nehu, the leading livebait fish for tuna in Hawaiian waters, were conducted for five important baiting areas in Hawaii. A total of 222 stomachs of fish from the commercial catch was analyzed for food contents. A gross quantitative analysis of the principal plankton species present in two areas was made for a comparison between the food items consumed and the organisms available.

Copepods, barnacle nauplii, and mysis larvae of shrimps were most important in the diet of nehu taken in Kaneohe Bay; ghost shrimps (*Leucifer faxonii*) predominated in

fish from Ala Wai Canal; in Honolulu Harbor nehu food was mostly crab megalopa, ghost shrimps, and small palaemonid shrimps; and copepods predominated in stomach contents of nehu from Pearl Harbor and Hilo Bay. Very little seasonal change occurs in the kinds and proportions of the more important dietary items.

Nehu are selective feeders in that they take only the crustacean elements in the plankton. Selection among certain crustacean types is apparent in some areas and is lacking in others.

The characteristically larger nehu in Ala Wai Canal and in Honolulu Harbor show a predilection for large crustacean plankters and a virtual disregard for the more abundant smaller crustacean types, whereas the usually smaller nehu of other areas ignore the few large types available and consume the smaller forms in about the same proportions as they occur in the plankton. The baiting areas which have an abundant supply of the larger crustacean elements in the plankton contain the largest fish, while those areas which support only a sparse population of these larger plankters, or none at all, contain the smallest fish.

Further study on the relation of vigor to size and of size to food available may indicate the principles underlying the apparent differences in size and vigor of nehu in the various baiting grounds.

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The Origin, Development, and Nature of the Spermatophoric Mass of the Spiny Lobster, *Panulirus penicillatus* (Oliver)[1]

DONALD C. MATTHEWS[2]

INTRODUCTION

ALTHOUGH MANY thorough investigations of crustacean spermatozoa have been made, few have included more than desultory accounts of the spermatophores. The material presented in this paper not only extends our knowledge of the biology of the spiny lobster *Panulirus penicillatus* (Oliver) through an account of the origin, development, and nature of its spermatophoric mass, but also suggests the method by which its spermatozoa are liberated.

Early cursory observations on crustacean spermatophores by Cavolini, Kölliker, and Schwammerdam, cited in Herrick (1895: 160), apparently failed to stimulate further interest in this direction, but possibly served to incite such workers as Grobben (1878), Hermann (1890), Sabatier (1893), Brandes (1897), Labbé (1903), and Koltzoff (1906) to investigate more thoroughly the nature of decapod spermatozoa. These early works illustrate the interest in the spectacular decapod spermatozoa to the neglect of the spermatophores.

With the exception of the early work of Herrick (*op. cit.*) on the reproductive system of the American lobster (*Homarus americanus*), investigations of the spermatophores of macrurans were singularly lacking until Dahlgren and Kepner (1908) attributed to the lobster and the crayfish a fluid which, secreted by the walls of their sperm ducts, not only served as a vehicle to carry the mass of sperm but also formed a semifluid covering around them. Dahlgren and Kepner further reported that the spermatophore attached itself to a receiving plate on the female, became hard, and preserved the life of the spermatozoa for months or even years. No reference is made however to the species of lobster and crayfish which produced these spermatophores.

No particular differentiation between the non-pedunculate spermatophores of the Macrura and the more bizarre pedunculate spermatophores of the Anomura and Brachyura was noted in the literature until Calman's treatise in 1909. Since that time considerable research has ensued on the pedunculate type, and, culminating in the studies of Mouchet (1930–31), the origin and development of these have become rather well known.

Comparatively little research has been accomplished on the non-pedunculate spermatophore of the Macrura. Allen (1916) first described for a spiny lobster, *Panulirus interruptus*, a spermatophore composed of a putty-like mass of sperm material. This mass, placed on the ventral surface of the female's thorax, contained contorted tubular cavities filled with spermatozoa. He further explained that this mass was at first white and soft but later turned black and became hard, resembling whalebone. Allen's account, as well as Fasten's (1917), on the consistency and color change in the spermatophoric mass of *Panulirus interruptus* is in accord with the findings of this report, but their observations on the contorted tubular cavities were not extensive and little consideration was given to the origin or the development of the mass. Insofar as can be ascertained, no published work on the origin, development, and nature of the spermatophoric mass of *P. penicillatus* has been reported.

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METHODS AND TECHNIQUES

Specimens of *P. penicillatus* taken in the vicinity of Kaneohe Bay, Oahu, between July, 1947, and January, 1948, were used in this study. Males whose carapace length exceeded 10 centimeters were usually found to possess well-developed gonads. These were removed from freshly killed specimens, rolled lightly on blotting paper, weighed, and placed immediately in fixative. A label indicating the catch and specimen number was inserted in each vial so that histological data could be correlated with size, date, and other pertinent information.

For the purpose of routine histological examination the reproductive system (Figs. 1, 2) was divided into: anterior testis (Fig. 2*i*); mid-testis (*e*); posterior testis (*c*); proximal vas deferens (*d*); and the massive distal vas deferens (*b*). Small portions of these regions were placed in Bouin's fixative, which gave excellent preparations for all tissue except the vas deferens which became extremely brittle. Tissues were cleared with toluene, embedded in Tissuemat (54–56° C.) and, for routine investigation, sectioned at 10 microns. Some testis preparations were placed in Bouin's fixative and some in Fleming's, and were cut at 6 and 4 microns. Routine sections were stained with standard alum-haematoxylin and counterstained with eosin (0.5 per cent solution in 90 per cent alcohol to which 04. cc. of 0.1 N HCl was added). Heidenhain's iron-haematoxylin without a counterstain was used with good results in some sections of the testis. Mallory's triple connective-tissue stain was employed to aid in tissue differentiation. Because of the extreme hardness of the enlarged portions of the vas deferens, it was often necessary to coat the surface of the paraffin block with thin celloidin between successive cuts. For examination of the rayed spermatozoa, fresh sections were taken from the enlarged vas deferens, the matrix was separated from the spermatophore, and the spermatophore was opened in sea water.

Figures 1 and 9 were drawn by Florence Lambeth from dissections made by the author. Figures 2, 4, 5, 6, 7, and 8 were drawn by Inger Achton from slides and dissections made by the author. Figure 3 was drawn by Evan L. Gillespie.

The writer acknowledges with thanks the help of Dr. Robert W. Hiatt, who suggested the problem and offered his assistance in many ways throughout the course of the study.

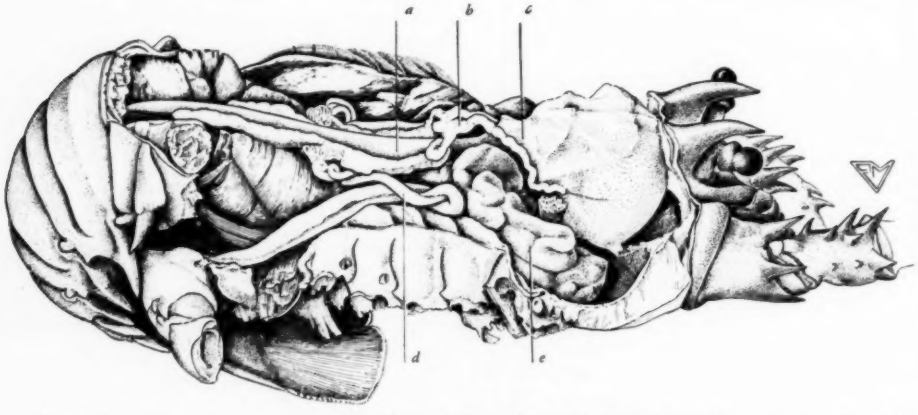

FIG. 1. Dissection of a mature male *Panulirus penicillatus* (Oliver) drawn to show the structure and position of the reproductive system in relation to other structures. *a*, Intestine; *b*, testis just anterior to transverse bridge; *c*, pyloric region of stomach; *d*, enlarged portion of vas deferens; *e*, hepatopancreas. (0.5×)

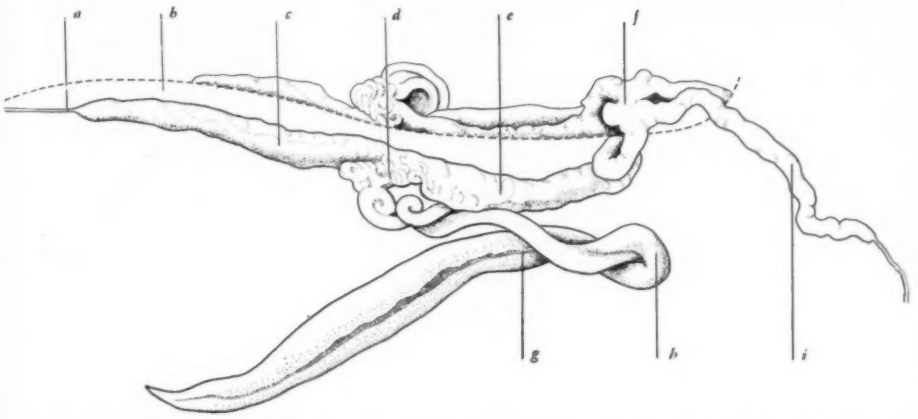

FIG. 2. Male reproductive system enlarged to show: *a*, posterior mesentery of testis; *b*, portion of the digestive tract; *c*, posterior region of testis; *d*, proximal portion of vas deferens; *e*, region of mid-testis; *f*, region of transverse bridges; *g*, hyaline line; *h*, enlarged, swollen portion of vas deferens; *i*, anterior region of testis. (1×)

RESULTS

The testes (Fig. 1*b*) are seen to be long, whitish, sacculate tubes joined one to the other by a transverse bridge (Fig. 2*f*) just posterior to the junction of the pyloric region of the stomach (Fig. 1*c*) with the intestine (*a*). Seen dorsally, the testes resemble an elongated **H** in which the posterior portion (Fig. 2*c*) usually exceeds the anterior portion (*i*) both in length and diameter. With the exception of the anterior distal portion of the testis which, as it encircles the stomach, extends ventrally, the major portion of the anterior testis lies dorsal to the hepatopancreas (Fig. 1*e*) and the digestive tract (Fig. 1*a*, 2*b*). The posterior portion of the testis traverses caudad on either side of the intestine, often slightly ventrad to the digestive tract. It is not uncommon to observe differences in the size of the testicular horns, the right posterior portion often being longer than the left, or vice versa. The testes are held in place by mesenteries (Fig. 2*a*) which extend posteriorly a short distance into the first abdominal segment, and anteriorly appear to be attached ventrad to the stomach.

At the outset of this study it became apparent that an understanding of the origin, development, and nature of the spermatophoric mass made necessary a thorough study of the histology of the testis. Only when the entire testis is studied in serial section can one properly interpret any single section or attempt the more difficult task of reconstruction. Throughout each general region of the testis, follicles observed in any one histological section exhibited various degrees of maturity, although the cells in any one follicle were usually at the same stage of development.

Figure 3 is a diagrammatic reconstruction of the testis. It suggests, somewhat, a paniculate inflorescence, but seems to be a racemose or compound gland of freely branching ducts which terminate in acini, so that the whole resembles a compact cluster of grapes. The reconstruction further shows that the racemose, anterior portion of the testis (*a*) joins ultimately the racemose, posterior portion of the testis (*b*) to form an exceedingly long and highly coiled tube (*c*). This contorted tube traverses the testis for some distance both anteriorly and posteriorly from its place of origin in the mid-testis (*d*) and ultimately emerges as the vas deferens (Figs. 1*d*, 2*d*, 3*e*).

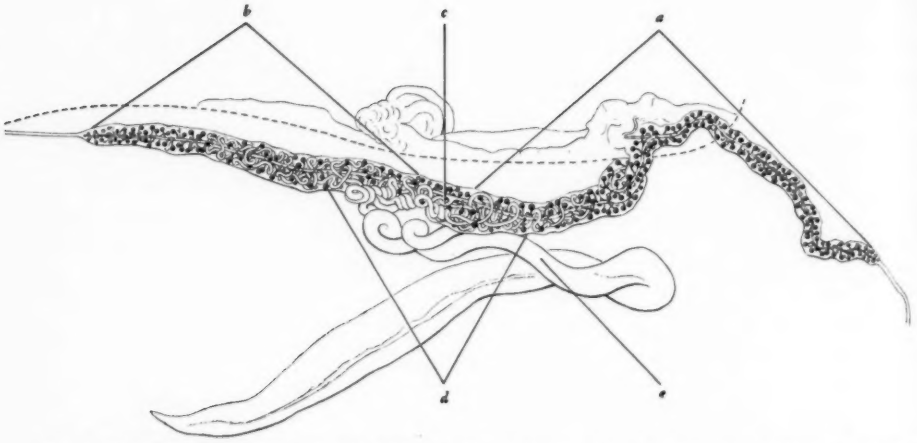

FIG. 3. Diagrammatic reconstruction of the right testis to show: *a*, paniculate anterior portion; *b*, paniculate posterior portion; *c*, tube which ultimately drains regions *a* and *b*; *d*, mid-testis; *e*, vas deferens. (1×)

Figure 4 is a cross section through an immature follicle taken through the anterior part of the testis (Fig. 2*i*). It should be borne in mind, however, that sections taken through the mid-portion of the testis (Fig. 2*e*) or the posterior portion of the testis (*c*) would reveal follicles of similar maturity, and these would also be associated with other follicles of varying degrees of maturity. The entire follicle is filled with large, primary spermatocytes (Fig. 4*b*). These cells measure 15 to 20 microns in diameter and contain nuclei that may attain a diameter of 10 to 14 microns. At this particular stage it is impossible to distinguish the primary spermatocytes from the seminiferous epithelium (Fig. 4*c*).

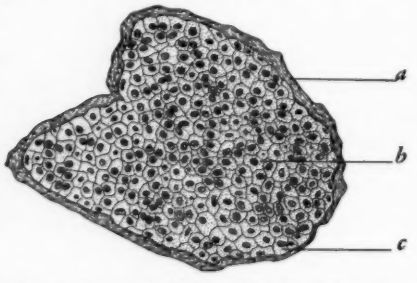

FIG. 4. Camera lucida drawing of portion of testis (Fig. 2*i*). *a*, Connective tissue; *b*, primary spermatocyte; *c*, seminiferous epithelium. (125×)

A transverse section (Fig. 5) as far posterior as the mid-testis (Fig. 2*e*) reveals follicles, some of which are more mature than that illustrated by Figure 4. Follicles at this stage of maturity likewise can be observed in transverse sections throughout the length of the testis, and these would also be associated with other follicles of varying degrees of maturity. A lumen (Fig. 5*g*) and radiating cells (*c*) present a wheel-like appearance in this stage of development. Whereas in Figure 4 the follicle is filled with a homo-

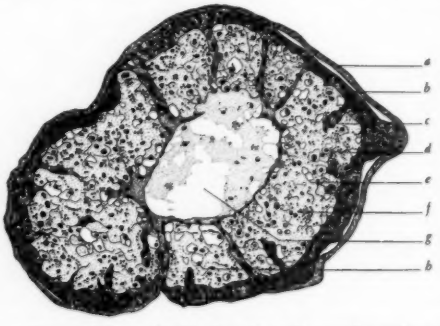

FIG. 5. Camera lucida drawing of a small portion of testis (Fig. 2*e*). *a*, Cumulative tissue; *b*, peripheral layer of epithelium; *c*, Sertoli cells; *d*, primary spermatocytes; *e*, secondary spermatocytes; *f*, spermatids; *g*, central lumen formation; *h*, disintegrating primary spermatocytes. (80×)

geneous mass of primary spermatocytes, in Figure 5 the follicle is filled with a heterogeneous assortment of cells (*d*, *e*, *f*, *h*).

Sections which show the sperm mass in the small collecting tubules are likewise encountered throughout the length of the testis. A longitudinal section of such a tubule (Fig. 6) reveals that a secretion from the epithelium (*b*) also contributes to the continuous sperm mass. Long, fibril-like structures (*c*) are clearly seen, the longitudinal axes of which are parallel to the flow of the sperm mass. The metamorphosing spermatids (*d*) are clumped in rather definite areas and the remainder of the sperm mass (*e*) is scattered indiscriminately. Sections throughout the testis reveal that these tubules coalesce with other similar tubules.

However, sections taken through the regions of the mid-testis (Figs. 2*e*, 3*d*), with the follicles and tubules already referred to, reveal a quite different tube. As indicated by the reconstruction, this tube (Fig. 3*c*) is formed by the juncture of the racemose anterior and posterior portions of the testis, and this highly contorted tube courses throughout a considerable length of the testis (Fig. 3*d*). In many specimens this tube often extends farther posteriorly than anteriorly. Figure 7 represents a cross section through this tube. The greater portion of the epithelium (*f*) is located in glands embedded in the wall of the tube. These glands open into the lumen (*c*) of the tube. The epithelial cells average 43 microns in length and, throughout the entire region, secrete both a mucus-like substance and a granular or crystalline substance (*b*). These "crystals," observed under oil immersion magnification, averaged 1.43 microns in length and were roughly hexagonal. Great masses of these "crystals" (*d*) surround the sperm mass (*e*).

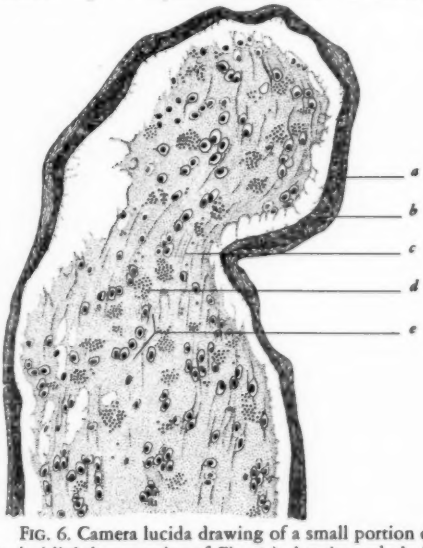

FIG. 6. Camera lucida drawing of a small portion of testis (slightly posterior of Fig. 2*e*) showing tubule in longitudinal section. *a*, Connective tissue; *b*, seminiferous epithelium; *c*, Sertoli fibrils; *d*, developing spermatids; *e*, degenerating primary spermatocytes. (75×)

ANATOMY OF THE VAS DEFERENS

Leading from each testis is a highly convoluted tube, the vas deferens (Fig. 1*d*), which,

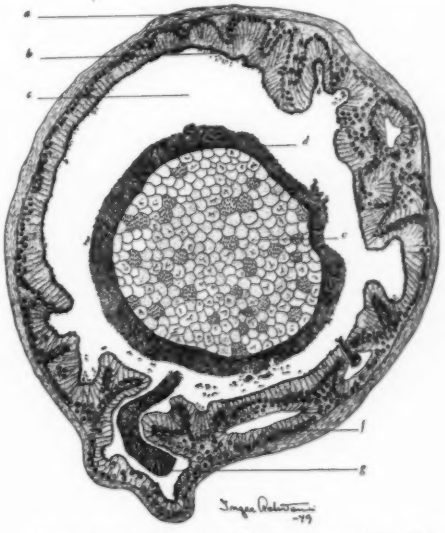

FIG. 7. Camera lucida drawing of a portion of the testis (Fig. 2*c*). *a*, Muscle and underlying connective tissue coats; *b*, crystal-like clumps of material near distal margins of epithelium; *c*, lumen; *d*, wall of spermatophore; *e*, sperm mass; *f*, gland embedded in wall; *g*, spermatophoric wall material exuding from gland. (65×)

increasing in diameter distally, conveys sperm from the testis to the genital pore, located on the coxopodite of the last pereiopod. The proximal portion (Fig. 2*d*), which is impossible to dissect free from the tissue of the testis, emerges to form the enlarged distal portion (Fig. 2*b*). Whereas the testis and certain portions of the vas deferens are opaque, the lateral surface of this enlarged portion of the vas deferens is demarked by a distinct hyaline line (*g*) which traverses its length.

Figure 8 is a typical cross section through the enlarged portion of the vas deferens (Fig. 2*b*). This portion of the vas deferens is characterized by the presence of a typhlosole-like structure (Fig. 8*c*) which projects from the hyaline line (Figs. 2*g*, 8*a*) into the lumen of the vas deferens (Fig. 8*b*). Both the glandular epithelium (*f*) of the "typhlosole," which here bounds deep crypts (*e*), and the connective tissue (*d*) are continuous with the wall of the vas deferens. The wall of the sperm mass (Fig. 7*d*) also appears in sections through the enlarged vas deferens (Fig. 8*g*) but is further embedded in a homogeneous matrix-like substance (*h*). Regardless of the stain used, the glandular secretion (*e*) of the crypt-like folds of the "typhlosole" (*c*) stain the same as the matrix (*h*). Usually, but not in all cases, this secretion takes the cytoplasmic stain.

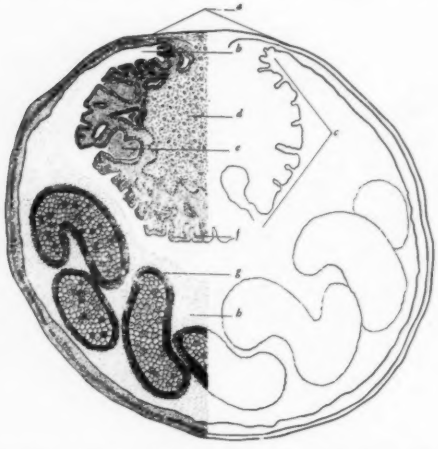

FIG. 8. Camera lucida drawing of a cross section of vas deferens (Fig. 2*b*). *a*, Hyaline line region; *b*, lumen of vas deferens; *c*, "typhlosole"; *d*, connective tissue; *e*, crypt; *f*, glandular epithelium; *g*, spermatophoric wall; *h*, matrix. (13×)

Dissection of the entire enlarged portion of the vas deferens (Fig. 9) along its lateral line reveals, even prior to flattening and fixation, a highly coiled continuous tube (*a*) embedded in a putty-like matrix (*b*). This tube appears as a yellowish "thread" occupying a position near the muscular wall of the vas deferens opposite the hyaline line.

In freshly killed specimens, peristaltic waves traverse the length of this enlarged portion of the vas deferens when it is pinched with forceps. This stimulation is adequate to cause the extrusion of the spermatophoric mass which in nature adheres to the sternum of the female, posterior to the opening of the genital pore.

Figure 10 illustrates a typical spermatophoric mass on a portion of the sternum (*b*) removed from a female whose carapace length was 9.5 cm. and whose carapace width was 7.6 cm. This specimen was taken off Kekepa Island, Oahu, January 23, 1948, by a tangle net set at 30 feet. The ovaries of this specimen were highly developed and ovulation was imminent. The spermatophoric mass, of about average size, was 4.2 cm. at its greatest width, 2.7 cm. at its greatest length, and approximately 0.5 cm. in thickness. The outer, exposed black portion of the mass (*c*) which could not be peeled off had the consistency of whalebone and averaged less than 0.5 mm. in thickness. As in other specimens, the spermatophoric mass displayed a certain bilateral symmetry suggesting that in its application both right and left vas deferens extrude their contents.

Dissection reveals that the homogeneous inner mass, the matrix (*a*), surrounds the highly coiled, continuous, spermatophoric tube (*d*). Lying under the undisturbed portion of the spermatophoric mass (Fig. 10*c*) is found

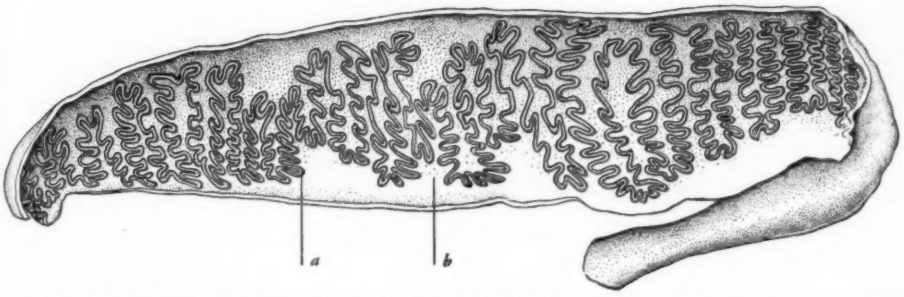

FIG. 9. The enlarged vas deferens dissected along its hyaline line to show: *a*, continuous spermatophore; *b*, region occupied by matrix. (10×)

another continuous spermatophoric tube surrounded by its matrix, products of the opposite or left side of the reproductive system.

DISCUSSION

Since the spermatophoric mass is an accumulation of materials derived from various regions of the male reproductive system, the specific contribution of each region will be discussed in its proper sequence.

By mitotic division, the entire follicle becomes filled with large, primary spermatocytes (Fig. 4*b*). Two processes become evident. From the peripheral layer of the epithelium (Fig. 5*b*) which lies adjacent to the tunica propria (*a*), deeply staining cells (*c*) appear which radiate toward the center of the follicle. At first these are few, some radiating in from one side and some from another. These increase in number without any definite order, creating a wheel-like appearance with the cells forming the "spokes." Care should be exercised in interpreting these early stages because quite often, in sections cut at an angle, these cells appear at the center of the already filled follicle without any relationship to the epithelium from which they arise. Their attached, proximal regions, therefore, would not be evident. Older follicles show these spokes thickened and, at first sight, containing many nuclei. In reality any one spoke is composed of many cells, closely packed together, all radiating toward the center of the follicle. The nuclei, which average 11 microns long and 5 microns wide, are smaller than those of the spermatocyte and more ovoid. These nuclei often appear notched and contain large, deeply staining granules. The reticular, fibrillar nature of the cytoplasm of these cells makes identification of individual cells exceedingly difficult. It should be mentioned that the sections, cut between 5 and 10 microns for routine investigation, are much too thick and too crudely stained for accurate interpretations of the cells. They appear to be Sertoli cells that have actually fused to form a syncytium. This cannot be determined, however, until a more suitable technique is employed.

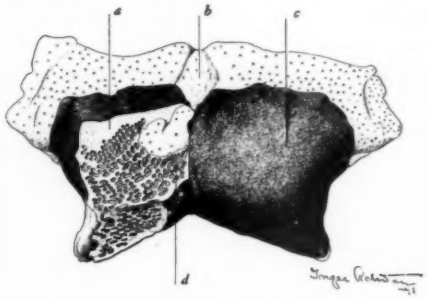

FIG. 10. Spermatophoric mass removed along with a portion of the female's sternum. Right side only dissected to show: *a*, matrix; *b*, sternum; *c*, exposed black portion of mass; d, spermatophoric tube. (1×)

Meanwhile, the second process becomes evident as some of the primary spermatocytes (*d*) undergo two successive divisions, the first

probably heterotypic, resulting in two secondary spermatocytes (*e*), and the second homeotypic, which divides the secondary spermatocytes into four spermatids(*f*). Other potential primary spermatocytes fail to complete the spermatogenic process. In these, small vacuoles appear in their cytoplasm, then coalesce to form a large vacuole which surrounds and often pushes the shrunken nucleus to one side of the cytosome (*b*). All stages of cell disintegration may be observed. The contents of disintegrated cells probably serve as nutrient material both during and after the metamorphosis of the spermatids to spermatozoa. If the central lumen (Fig. 5*g*) that forms in the once compact follicle (Fig. 4) is the result of the action of Sertoli cells, it is possible to assume that what appears to be a lumen bounded by a syncytium of Sertoli cells is in reality the distal portions of many Sertoli cells already containing spermatids. Scattered in between these cells is found the debris of disintegrating primary spermatocytes. In any event, the diameter of the lumen increases and the "ring" of Sertoli cells which surrounds the mass moves toward the periphery of the follicle until, finally, only a single layer of epithelium remains.

A longitudinal section of a collecting tubule (Fig. 6) reveals that the epithelium (*b*) in this region appears to contribute a mucus to the continuous sperm mass. Whether this material serves a nutritive or lubricative function was not determined. Long fibrils (*c*), the longitudinal axes of which lie parallel to the flow of the sperm mass, are clearly seen. It should also be pointed out that, whereas the developing spermatids (*d*) clump in rather definite areas, the remainder of the sperm mass (*e*) is scattered indiscriminately. These tubules, which contain the continuous sperm mass, coalesce with other similar tubules until finally, in the mid-region of the testis (Figs. 3*c*, *d*), sections are encountered which possess structures identical with those shown in Figure 7.

When a comparison is made of sections here illustrated by Figures 6 and 7, the presence or absence of a spermatophoric wall (Fig. 7*d*) is not the only significant difference to be seen. The deposition of this wall (Fig. 7*d*) could possibly account for the compactness of the sperm mass, but could scarcely account for the distinct, cell-like membranes which isolate the developing spermatids into distinct clumps. Whereas the longitudinal sections of the collecting tubule (Fig. 6) present the effect of streaming fibrils (*c*), cross sections through the tube (Fig. 7) clearly show these to be portions of Sertoli cells (*e*) cut at right angles to their longitudinal axes. Whether this isolation into clumps of developing spermatids is due to their having been contained within Sertoli cells that have become liberated, or whether the developing spermatids are mechanically isolated by the pressure of the other cells, is difficult to ascertain. It appears very unlikely, however, that the clumping of the developing spermatids is due to an increase in intercellular pressure because these clusters are first observed in sections of follicles where the lumen (Fig. 5*g*) is just forming, and when the pressure would be negligible. The occurrence of spermatid clusters in the region of initial lumen formation strongly suggests that the spermatids in each cluster represent those individuals that develop within a given Sertoli cell, and that, as the Sertoli cell is sloughed off, the contained developing spermatids remain encompassed.

As previously noted, the wall of the spermatophore (Fig. 7*d*) is encountered when the sperm mass of the collecting tubules (Fig. 6) has reached the position indicated by Figure 3*c*. Throughout the length of this highly coiled tube which traverses the testis for some distance both anteriorly and posteriorly (Fig. 3*d*) the glandular epithelium of its wall secretes the material which surrounds and forms the true wall of the spermatophore. Although the thickness of the spermatophoric wall increases as this portion of the tube is traversed, neither the overall diameter of the

spermatophore nor the thickness of its wall increases once the walled spermatophore enters the enlarged vas deferens. For this reason, together with the fact that the secretion (Fig. 7*g*) from the epithelium of this tube stains identically with the material (*d*), the deposition of the spermatophoric wall is attributed to this tube.

The walled spermatophore (Fig. 7*d*), upon entering the enlarged vas deferens (Fig. 1*d*), becomes surrounded by a putty-like matrix (Fig. 8*b*) which is formed largely by the secretion from the "typhlosole" (Fig. 8*c*). The position of the walled spermatophoric tube (Fig. 8*g*), embedded in the matrix near the wall opposite the "typhlosole," appears explainable by the fact that, although the glandular epithelium of the peripheral wall of the vas deferens may secrete some matrix, the glandular epithelium of the "typhlosole" secretes most of it, and the extensive production of matrix from this region forces the walled spermatophoric tube toward the periphery of the organ. There is no evidence that the wall of the spermatophore (Fig. 8*g*) is formed by this matrix material. Since the hyaline line (Fig. 2*g*) marks externally the position of the internal "typhlosole," it appears hyaline because the dense matrix between the "typhlosole" and the wall of the vas deferens is here lacking.

Although in nature the actual process of extrusion and adherence of the spermatophoric mass was not observed by the author, the process was experimentally performed for subsequent observation. While immersed in sea water, the vas deferens of a mature male *P. penicillatus* was exposed and pinched with forceps. This served as a sufficient stimulus to cause the extrusion of the spermatophoric mass. This mass was smeared on the sternum of a living female, on a piece of sternum which had been removed from an adult female, and on a clean glass plate. The smeared piece of sternum and the smeared glass plate were suspended by threads in the same aquarium with the artificially smeared female. Within the first hour all the smears darkened slightly, but even after 14 days this darkening had progressed only to a light brown color, the masses never attaining the hardness or the darkness of the spermatophoric mass found deposited naturally. The smear on the isolated pieces of sternum and the smear on the glass plate were eagerly sought after and eaten by the reef fish, *Alectis ciliaris* (Bloch). The smears apparently darkened only superficially, for, when viewed through the glass, the unexposed surface could be seen to retain its putty-like appearance. Attempts were also made by this fish to obtain the smear placed on the living female, but she would quickly retreat to a corner of the aquarium or otherwise protect the mass with the telson of her flexed abdomen. During the 14 days of observation this female made no attempt, however, to remove the mass. At the end of this period, the spermatophoric mass was examined carefully and, except for a few superficial sand scratches, the mass was unaltered. The ovaries were then examined and found to be immature. The spermatozoa, however, in the artificially applied spermatophore were still alive. Although this experiment was repeated several times in an attempt to obtain a female in which ovulation was imminent, all efforts failed. In those mature females which obviously had ovulated, the spermatophoric mass was deeply scratched or gouged, and the spermatophores were devoid of spermatozoa.

Andrews (1931), working on the Oregon crayfish (*Potamobius trowbridgei*), was concerned with the manner of liberation of the spermatozoa and stated: ". . . the suggestion was made by Leuckart that by the gradual change of the wall of the spermatophore, (a secretion from the lining cells of the deferent duct), a discharge of sperms might be caused; but this would need be accurately timed. Very likely, as surmised by Meyer, it is the action of some secretion of the female at the time of laying eggs which induces the emptying of the spermatophore." Andrews

mentioned that the spermatophores exhibited free, distinct ends, and their bases were stuck together more or less indistinguishably. The fact that Andrews observed spermatophores over a widely scattered area on the female might possibly be due to the inability of the male to hold fast the female. Since only one case was cited by Andrews, the question arises as to whether this scattering of the spermatophores is the normal manner of application. No mention was made regarding the origin or nature of the adhesive substance, but careful examination of many testis sections of *Potamobius* sp. (prepared commercially by Albert E. Galigher, Inc., Berkeley, California) often reveals a continuous sperm mass enveloped by a spermatophoric wall. Since the developing spermatophore from each testis is in reality a continuous tube, it is possible that the spermatophore in the exuded spermatophoric mass might also be a continuous tube (or two tubes, if each vas deferens contributed simultaneously), as has been shown in *P. penicillatus*. Hurried, intermittent expulsions of the spermatophoric mass by contractions of the muscular vas deferens could account not only for the scattered spermatophoric masses, but also for the formation of the continuous spermatophoric tube into what appears to be separate, distinct spermatophores.

Both Andrews, working with an astacid, the Oregon crayfish, and Herrick (1895), working with the American lobster, a homarid, believe that fertilization is external. On the other hand, von Bonde (1936), working with a palinurid, the Cape crayfish *Jasus lalandii* (Milne Edwards) Ortman, believes fertilization is internal. He describes the condition in *Jasus lalandii* in which the receptaculum seminis of *Homarus americanus* is absent, its counterpart in the position of this structure being only a shallow depression. He further states that this depression is almost covered with hard setae in the living animal and only appears evident in dried specimens, a feature which, he believes, would preclude its use as a receptaculum seminis. The lack of a seminal receptaculum in *Jasus lalandii*, together with the fact that its eggs, when laid, possess an outer membrane of chitin, seem to von Bonde to preclude the possibility of external fertilization and to require that fertilization take place in the oviduct before the chitinous layer is deposited. Moreover, in observations of females after mating and before egg laying, he saw no sign of spermatic fluid on the sternum. Von Bonde concurs with Yonge (1938) that fertilization takes place at the proximal end of the oviduct, and that no difficulty would be encountered by the sperm in achieving fertilization inasmuch as it would need only to penetrate the thin chorion of the egg rather than an outer membrane of chitin. Von Bonde did not explain how impregnation takes place, but it is evident that it is quite different from the manner described herein for another palinurid, genus *Panulirus*.

Crawford and De Smidt (1923) describe the spermatophoric mass for *Panulirus argus* as ". . . composed of two different substances. One substance, which hardens soon after being deposited upon the sternum of the female, forms the bulk and body of the vesicle, while the other substance remains liquid. This liquid does not harden, since it can be expressed when the surface of the vesicle is scraped away. These two substances . . . are probably separated from each other by the process of hardening of the waxy material around the liquid, the pores being formed in a way analogous to the air bubbles in thick glue, or molten glass. . . ." These interpretations are obviously faulty, as demonstrated by my examination of transverse sections of the vas deferens and of the freshly dissected lower portion of this structure.

Wilson (1948), quoting from the unpublished work of Fry (MS.) on the spiny lobster, *P. interruptus*, states, "The presence of putty on the ventral side of a female's carapace is no evidence of maturity as many im-

mature individuals carry sperm. On the other hand, during the breeding season with the exception of a few who had recently cast their shells, no mature female was found which did not have putty or evidence of its former presence." No attempt was made to investigate the contents of the putty-like masses.

The spermatophoric mass on females of *P. penicillatus* which have extruded their ova is deeply scratched; the gouges exhibit a roughened surface and extend through the black, exposed surface, through the matrix, and through the wall of the spermatophoric tube. Figure 10 shows the left side of the spermatophoric mass intact and without deep gouges. When sectioned (right side), the spermatophore contained motile spermatozoa. It should be recalled that this female would probably have discharged her ova presently. Where evidence of the former spermatophoric mass remained, it was deeply gouged, and the exposed, torn spermatophore of both the right and the left side was empty.

Many theories have been advanced for the liberation of spermatozoa from the spermatophore. That the rosette glands of the female's integument may produce a substance which dissolves the capsules of the spermatophoric wall may hold true for the delicate pedunculate spermatophores of the Anomura and Brachyura, but this method of liberating spermatozoa seems very unlikely for *P. penicillatus*. A chemical reaction that would liberate the spermatozoa would have to be exactly timed so that spermatozoa would be available the instant the ova were released. Even so, such action could scarcely have produced the deep, jagged gouges one observes on the spermatophoric mass of *P. penicillatus*. It seems much more reasonable to assume that the spermatozoa are liberated by the scratching action of the female's pereiopods, a method in accord with the observations of Crawford and De Smidt (1923) on *P. argus* and Smith (1948) on *P. interruptus*.

CONCLUSIONS

The H-shaped testis of *Panulirus penicillatus* (Oliver), when reconstructed from serial sections, is found to be a racemose or compound gland of freely branching ducts which terminate in acini. The racemose, anterior portion of the testis joins ultimately the racemose, posterior portion of the testis to form a highly contorted tube. This tube, imbedded in the tissue of the testis, traverses for some distance both anteriorly and posteriorly the region of the mid-testis. Cross sections throughout the entire testis show follicles in various degrees of maturity, although the cells in any one follicle usually exhibit the same stage of development.

The immature follicle becomes filled with potential primary spermatocytes by mitotic division of its seminiferous epithelium. A heterotypic, followed by a homeotypic, division of these cells results in the formation of spermatids. Other potential spermatocytes fail to complete the spermatogenic process, and all stages of disintegration of these cells are observed. Further development within the follicles is attributed to the action of Sertoli cells which, arising from the germinal epithelium, encompass the spermatids. The formation of a lumen, giving the follicle a wheel-like appearance, is attributed to the sloughing off of these Sertoli cells.

Longitudinal sections through the collecting tubules show the sperm mass to be composed of four main components: developing spermatids, disintegrating spermatocytes, a nutrient substance, and portions of sloughed-off Sertoli cells. The evidence of spermatid clusters in the region of initial lumen formation as well as in sections of the collecting tubules strongly suggests that the spermatids in each cluster represent those individuals that develop within a given Sertoli cell.

The continuous sperm mass receives its spermatophoric wall from the tube formed by the juncture of the anterior and posterior racemose portions of the testes. The thickness

of this wall increases as this portion of the tube is traversed, but the diameter of the spermatophoric tube remains constant as the enlarged vas deferens is traversed. There is no evidence that the enlarged vas deferens of *Panulirus penicillatus* contributes to the formation of the spermatophoric wall.

The hyaline line of the enlarged vas deferens is associated with a highly glandular typhlosole-like structure. This "typhlosole" produces the bulk of the homogeneous matrix which surrounds the continuous spermatophoric tube. By contraction of the muscular walls of both vas deferens, the spermatophoric mass is exuded.

The spermatophoric mass placed on the sternum of a mature female exhibits a certain bilateral symmetry showing that both the right and left testes and vasa deferentia contribute in its formation. This mass consists of two main components: a continuous, highly convoluted tube—the spermatophore proper—and a putty-like matrix in which the spermatophore is embedded. The spermatophoric mass artificially placed on the sternum of a female hardens and darkens slightly within an hour, but even after 14 days this darkening progresses only to a light brown color, without attaining the hardness or the darkness of the spermatophoric mass found deposited naturally.

Whenever the spermatophoric mass is found scratched or deeply gouged it proves to be devoid of sperm, whereas, if it is found intact, viable sperm are present. Thus, a mechanical method of scratching or gouging the spermatophoric mass for the liberation of the spermatozoa rather than by chemical dissolution is proposed for *Panulirus penicillatus* (Oliver). This method provides ample sperm during ovulation and precludes the probability of internal fertilization.

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The Luminescence of Some Deep-sea Fishes of the Families Gadidae and Macrouridae

YATA HANEDA[1]

INTRODUCTION

WHILE STUDYING THE JAPANESE FISH *Physiculus japonicum* Hilgendorf, of the family Gadidae, Franz (1910) noticed a round black pigmented spot situated ventrally and in front of the anus. He studied its structure, but was unable to explain its physiological function.

Later Kishitani (1930) examined this organ and discovered it was an open type of luminous organ containing symbiotic luminous bacteria. He described its structure and gave a specific name to the bacterium, *Micrococcus physiculus*. He could not see any luminosity while the fish was living under natural conditions, and concluded that the luminous organ merely produced luminous bacteria which were ejected occasionally as a luminous cloud into the surrounding sea water.

In August, 1936, I had an opportunity to observe this fish in the dark in an aquarium tank at the Asamushi Marine Biological Station of Tohoku University. Among many other fishes in the tank, I saw one which I had never seen before, which emitted light from this ventral spot. It did not eject a luminous cloud of matter.

In August, 1937, I observed another species of the Gadidae, *Lotella phycis* Temm. & Schl., which also possessed a similar type of luminous organ, from the duct of which I was able to culture luminous bacteria in artificial media.

The fishes of the family Macrouridae are closely related to the Gadidae and have a luminous organ of the same type. Their luminosity was first recorded by Osorio (1912). One species of the family, *Malacocephalus laevis* (Lowé), has the same type of luminous organ, similarly situated. Osorio stated that it was a practice of the Portuguese fishermen to force luminous matter from the organ by pressing it against pieces of shark flesh which they used as bait. In this way the flesh became luminous, and so was improved as bait for their fishing. This led him to believe that the luminous matter consisted of luminous bacteria, but since he was unable to culture any he could not confirm his belief.

Hickling (1925, 1926) described the structure of the luminous organ of this fish, and stated that it was of a new type, the luminous matter in the organ consisting of luminous granules. In 1931 the same author described the luminous gland of *Coelorhynchus coelorhynchus* Risso, also as a new type of luminous organ containing a luminous granular substance.

Yasaki and Haneda (1936) reported that there were 10 species of the Macrouridae with luminous organs, from the ducts of which they cultured luminous bacteria in artificial media.

In 1938 I examined *Malacocephalus laevis*, described its luminous organ and the contents, and cultivated luminous bacteria from it. Imai (1942) made bacteriological examinations of material from five species of the Macrouridae.

Recently Parr (1946) has studied many macrourid fishes of the western North Atlantic and the Central American seas. He recognized the outer aspect of the luminous organs on the ventral regions of fishes of the genera *Hymenocephalus*, *Malacocephalus*, *Ven-*

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trifossa, *Nezumia*, *Grenurus*, *Trachonurus*, and *Coelorhynchus* as a lens-shaped body, or scaleless "fossa" or naked area.

I have collected and studied the comparative structures of the luminous organs of many specimens of various species, and I have also cultivated their bacteria in artificial media. The results of these observations are presented here.

Acknowledgment: I wish to express my sincere gratitude to Dr. Pletsch, Scientific and Technical Division, ESS, GHQ, SCAP, who helped me in gaining publication of this paper.

MATERIAL

Altogether I have examined material from two species of the Gadidae and 14 species of the Macrouridae.

The Gadidae are comparatively shallow-water fish. They may be caught close to the coast of Japan. *Physiculus japonicus* occurs in water varying in depth from 30 to 50 fathoms. *Lotella phycis* is sometimes taken in extremely shallow water near the surface. This enables one to keep them in an aquarium tank where each can be observed in a natural state. They may be caught at any time of the year by hook and line, and their luminosity may be seen if they are taken during the darkness of the night. *Physiculus japonicus* is occasionally taken by trawlers.

The Macrouridae are always caught by trawlers since they are deep-water fishes living in over 100 fathoms of water. They are taken most abundantly during the winter in Japan.

STRUCTURE OF LUMINOUS ORGANS

Studies made up to the present time show that the Gadidae and Macrouridae possess the same open type of luminous organs. These organs may consist of the following four components: (a) A luminous gland; (b) its canals and their openings; (c) lenses with an external ventral aperture covered with a thin transparent skin through which light is transmitted; and (d) a reflector and chromatophores.

In some species the luminous gland may be so small as to be almost invisible. The canal leading from the gland may be either very short or very long. The structure of the lens may be very complicated, or very simple and inefficient. The reflector may vary also in its efficiency according to its structure.

The external ventral aperture through which light is transmitted is visible externally and may be comparatively large, or very small, or it may be absent. It may be bean-shaped, or circular, or very long and filiform, and in some species there may be two external apertures. The figures illustrate the many forms which can be seen. In the first type the luminous organ is very small and barely visible (as in *Coelorhynchus anatirostris*). It has a very short luminous duct, and is situated very close to the anus lying ventrally in the muscles, and has neither reflector, lens, nor external aperture. The organ cannot be seen externally, and gives the impression that it does not exist. Only when the fish is sectioned longitudinally and a cut is made through the organ can it be seen that there is a luminous duct which is extremely small and inefficient. In this duct are luminous bacteria. Although it is vestigial, it is nevertheless a true luminous organ, difficult as it is to determine.

Coryphenoides garmani and *C. misakius* are two other species which have very short and inefficient luminous ducts. The lenses and external apertures are inefficient, and from a casual inspection it is difficult to say whether they are luminous or not. However, luminous bacteria live in the duct of the gland.

In what may be considered the normal type or the typical luminous organ—such as that found in *Physiculus japonicus*, *Lotella phycis*, *Abyssicola macrochir*, *Coelorhynchus kishinouyei*, *Coelorhynchus japonicus*, and *Nezumia condylura* —the organ consists of a rather large luminous gland, the reflector, the lenses, and a scaleless external aperture covered with thin transparent skin. The canal in some species is rather long and in others very short; for

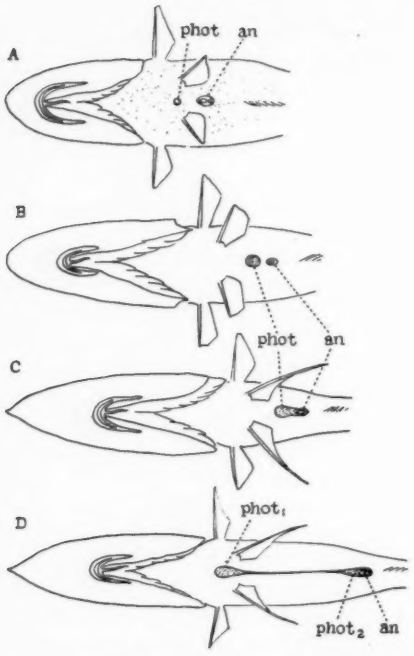

FIG. 1. Diagrams of the luminous organs of some Macrouridae. *a, Coryphaenoides garmani; b, Abyssicola macrochir; c, Coelorhynchus japonicus; d, Coelorhynchus hubbsi.* phot, luminous organ; an, anus.

example, *C. japonicus* has a very short canal with the external aperture close to the anus.

Some species have two scaleless external ventral apertures. Examples of this type are *Malacocephalus laevis* (Lowé) and *Malacocephalus nipponensis*, each of which has two external apertures, one bean-shaped and one round. The inner structure is of the normal type, i.e., it has a large luminous gland, a reflector, two lenses, and two external apertures. Their structure has been described by both Dr. Hickling and myself.

The canal is very long in some species, such as *Coelorhynchus parallelus* and *C. tokiensis*. The canal itself functions as a luminous gland with a long reflector, a poor lens substance, and no external aperture. However, one can see the long luminous duct through the transparent scales on the lowest part of the abdomen.

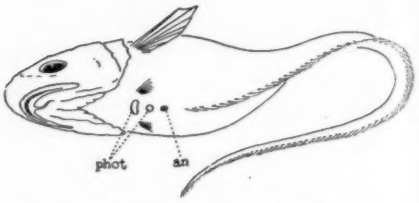

FIG. 2. *Malacocephalus laevis* (Lowé). phot, luminous organ; an, anus.

In their young stages these fishes are very strange, and only in this stage are they strongly luminous, the luminosity being visible ventrally as a single line. When full grown, this thin duct is covered with black pigment, which renders it useless as a luminous component in spite of the fact that luminous bacteria are living within it. The luminosity of *Coelorhynchus coelorhynchus*, as described by Hickling (1931), may be due to the fact that perhaps he saw a young specimen, as it is probable that this species is very similar to the two species under discussion.

Coelorhynchus hubbsi Matsubara has an extremely thin, long canal, each end of which is swollen into a club-shaped gland. The

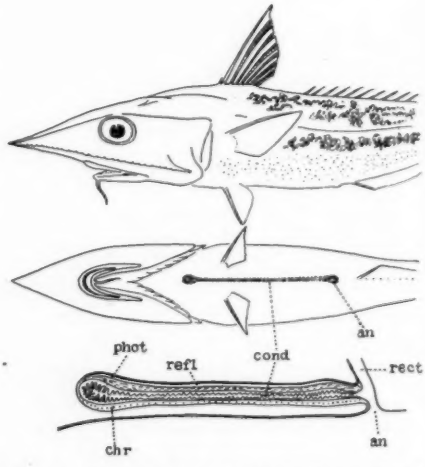

FIG. 3. Diagram of the luminous organ of *Coelorhynchus parallelus* and its longitudinal section. phot, luminous gland; refl, reflector; cond, conduit; chr, chromatophore; an, anus; rect, rectum.

TABLE 1

DATA ON COLLECTIONS OF LUMINOUS GADIDAE AND MACROURIDAE

SPECIES	PLACE OF COLLECTION	DATE OF COLLECTION
Coryphaenoides garmani Jordan and Gilbert Sagami-Sokodara*	Chōshi fish market, Chiba Prefecture.. Mimase fish market, Kōchi Prefecture	Nov., Dec., 1934 Jan., Mar., 1935
Coryphaenoides misakius Jordan and Gilbert Misaki-Sokodara*	Chōshi fish market.....	Nov., Dec., 1934 Jan., Mar., 1935 Jan., 1936
Abyssicola macrochir Günther..... Tenaga-dara*	Chōshi fish market.....	Oct., Nov., Dec., 1934 Feb., Mar., 1935
Coelorhynchus anatirostris Jordan and Gilbert Nezumi-Hige*	Chōshi fish market.....	Nov., Dec., 1934 Feb., 1938
C. japonicus Temm. and Schl..... Tojin*	Mimase fish market.....	Mar., 1935 Feb., 1938
C. kishinouyei Jordan and Snyder..... Mugura-hige*	Numazu fish market, Shizuoka Prefecture Heta fishing village, Shizuoka Prefecture	Mar., 1935 Mar., 1938
C. parallelus Günther..... Soroi-hige*	Mimase fish market.....	Jan., Mar., 1935 Mar., 1938
C. tokiensis Steindachner and Döderlein..... Nezumi*	Mimase fish market.....	Jan., Mar., 1935
C. hubbsi Matsubara..... Moyō-Hige*	Mimase fish market.....	Nov., 1934 Mar., 1935 Mar., 1938
Nezumia condylura Jordan and Gilbert..... Nezumi-dara*	Chōshi fish market.....	Nov., Dec., 1934 Mar., 1935
Malacocephalus laevis (Lowé)..... 	Mimase fish market.....	Apr., 1935 Jan., Apr., 1936
Hymenocephalus striatissimus Jordan and Gilbert Suji-dara*	Mimase fish market.....	Apr., 1935 Apr., 1938
H. Kuronumai Kamohara..... Yari-dara*	Mimase fish market.....	Mar., Apr., 1938
H. gracilis Gilbert and Hubbs..... Hoso-suji-dara*	Mimase fish market.....	Mar., Apr., 1938
Physiculus japonicus Hilgendorf..... Chigo-dara*	Mimase fish market..... Chōshi fish market Asamushi Marine Biological Station, Aomori Prefecture Misaki fish market, Kanagawa Prefecture	Jan., Apr., 1935 Apr., 1937 Aug., 1938 Aug., 1938
Lotella phycis Temm. and Schl.....	Misaki Marine Biological Station, Kanagawa Prefecture	Aug., 1938

* Japanese name.

ventral area is scaleless and there are two external apertures. Behind the swelling at the posterior end is a reflector. By examining fresh material in the dark, two luminous points can be seen.

The combination of a very long canal and a compound lens occurs in some species, such as *Hymenocephalus striatissimus* Jordan and Gilbert, *H. gracilis* Gilbert and Hubbs, and *H. kuronumai* Kamohara. In these there is a long, thin canal at the end of which is a club-shaped luminous gland to which is attached, ventrally, a swollen pouch-shaped body. This is a lens. Just behind and below it in the skin of the abdomen is a swelling which is doubly convex. This is a second lens which directs the light ventrally to the outside. It is a very complex organ. This type of luminous organ has already been reported by Vinciguerra (1932).

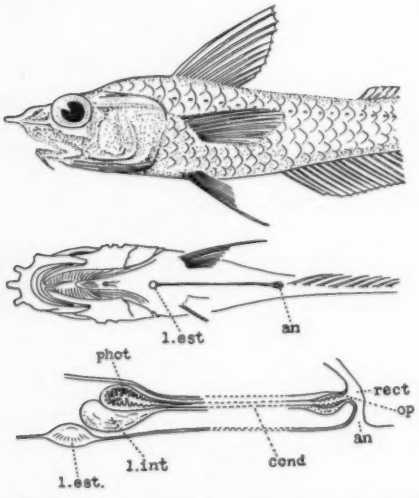

FIG. 4. Diagram of the luminous organ of *Hymenocephalus kuronumai* and its longitudinal section. phot, luminous gland; l.est, external lens; l.int, internal lens; cond, conduit; an, anus; rect, rectum; op, opening of conduit.

All of these are luminous glands and their innermost surfaces are lined with a layer of epithelial cells. Within the cavities formed by the folds of the glands resting on the inner ends of the epithelial cells are other cells which contain capsules in which are masses of bacteria, variously arranged. Some of these capsules are entire and contain the bacteria, others are ruptured and have allowed the bacteria to escape into the fluid of the gland ducts. Hickling says these masses are granules of luminous matter and that they exist in four states, viz.: (a) as closely packed masses filling their capsule; (b) as closely packed masses, but only half filling their capsule; (c) as loosely packed individuals in a ruptured capsule; and (d) as dispersed individuals free from their now empty capsule.

Both Kishitani and I, however, consider these so-called luminous granules to be masses of luminous bacteria. We have examined a great amount of material from many species and it all shows the same characteristics.

LUMINOUS PHENOMENA OF THESE ORGANS WHEN SEEN IN DARKNESS

Inasmuch as *Lotella phycis* and *Physiculus japonicus* live in comparatively shallow water, they can be kept in aquaria where their luminosity, if visible, could be seen in the dark. I have kept many specimens under observation but almost all of them displayed no luminosity which could be seen externally.

In August, 1936, while working at the Asamushi Marine Biological Station, I had a further opportunity to observe these fishes in the dark. Among many specimens of *Physiculus japonicus* in an aquarium tank, I saw one fish with a luminous ventral aperture. This aperture could be seen only when the fish swam upwards and thus showed its ventral surface. It could not be seen when it swam downwards from the top of the tank, showing only its dorsal surface, or when it swam horizontally, showing either one of its lateral surfaces.

I could not see any luminous, cloudy discharge from the opening, as had been suggested, and this led me to believe that the luminosity arose from a true luminous organ,

and that the difficulty in seeing it was due to the expansion of the chromatophores in the transparent, scaleless skin which covers the outside of the aperture. When these chromatophores expand they shut off the light and when they contract the light is transmitted and can be seen. Possibly the expansion and contraction may be determined by the water temperature, the degree of darkness or light, or by other factors, but I did not determine the effects of these factors upon the functioning of the chromatophores.

However, from my observations I am of the opinion that when these fishes are swimming in natural conditions at the bottom of the sea they are normally luminous, emitting light through these ventral apertures.

I have never been able to observe any macrourid fish in a natural condition since they are all deep-sea fish and cannot be kept in an aquarium. I have been able to examine only dead and living material freshly caught by trawlers from deep water. When examining this freshly caught material I could see the luminosity of some, but not of others. When the glands were cut open, however, they were always luminous.

The luminosity of young *Coelorhynchus parallelus* may be seen as a beautiful green filiform line on the ventral surface. *Coelorhynchus hubbsi* has two luminous spots on the ventral surface, and I am of the opinion that these fishes, when in their natural conditions, normally display their luminosity.

I cannot agree with the opinion that these fishes, through the opening of the canal in the anal region, discharge a luminous cloud into the surrounding sea water.

CONTENTS OF THE LUMINOUS DUCTS

Emulsions of the contents of the ducts were made in sterile sea water and were examined in the dark.

When first made, the emulsion was uniformly luminous. After standing in vertical tubes and settling for 20 minutes, the luminosity had collected as an upper layer. When shaken up, it was again uniformly distributed in the tube. If it was centrifuged, the luminosity was concentrated in the sediment at the bottom of the tube and the fluid above was clear and not luminous. If this precipitate was well mixed with sterile sea water the whole mixture became uniformly luminous, but if it was mixed with sterile distilled water, it failed to show any luminosity.

Changes of temperature showed the following results. Luminosity was greatest between 15 and 23°C. and this is the optimum temperature; at 0° C. it ceased; at 3–4° C. it was very weak; at temperatures between 23° and 45° C. it decreased; above this point it finally ceased and could not be reactivated when cooled again to 15–23° C.

The reactions were those of luminous bacteria and an examination under the microscope showed bacteria and segments of the gland duct cells. The bacteria stained red with Ziehl's solution and I was able to culture them by the usual bacteriological methods. Samples were taken from the organs of every fish studied. The characteristics of the luminous bacteria from the luminous ducts of many species of fishes of the Gadidae and the Macrouridae were investigated by the usual methods of culture in artificial media.

I was able to obtain 10 strains of luminous bacteria from each of these fishes—*Lotella phycis*, *Malacocephalus laevis*, *Hymenocephalus gracilis;* 20 strains of luminous bacteria from *Coelorhynchus kishinouyei* and *Nezumia condylura;* and 14 strains from the other species.

These strains of bacteria were taken from various species of fish taken at different times and in different localities. All had the same general biological characters but the optimum temperature, that is, the temperature at which the luminosity was greatest, varied. In some cases it was higher than others, but it never varied much. The optimum temperature for luminosity was lower for the bacteria of those fishes which live in deep and therefore colder water than for those living in the shallower and warmer water. A more complete discus-

sion of these bacteria will be presented in a separate paper.

SUMMARY

Some of the fishes belonging to the families Gadidae and Macrouridae are luminous and possess the "open type" of luminous organ containing luminous symbiotic bacteria. It consists of a gland in the ventral muscles lying in a scaleless depression between the pelvic fins. This is a characteristic of these fishes. Their luminescence is controlled by means of chromatophores. Normally they are deep-sea fishes although at times some of the Gadidae may be caught in shallow water. Observations were made on 14 species of the Macrouridae and 2 species of the Gadidae. Their luminous ducts are very similar but vary in size. In some species they are very long, in others very short, and in others extremely small and not visible from the outside. Some of the luminous ducts are of a comparatively simple construction while others are extremely complex.

I consider the luminous symbiotic bacteria which were cultured from these many fishes to be a species of the new group of luminous bacteria, but a more complete discussion will be presented later in a separate paper.

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Fabricinae (Feather-duster Polychaetous Annelids) in the Pacific[1]

OLGA HARTMAN[2]

THE UPPER LAYERS of mud in tidal basins such as sloughs and lagoons of various parts of the world are often abundantly populated by minute worms of widely related annelids, for example, *Streblospio benedicti* Webster of the family Spionidae, *Capitella capitata* (Fabricius) of the family Capitellidae, and several species of Sabellidae, subfamily Fabricinae, discussed below. Estuarine worms of this kind may occur in prodigious numbers over considerable areas. Since they are usually very small (a few millimeters long), inconspicuously colored, and covered with slime and debris, they are easily overlooked. Because of their abundance and slime-secreting properties they may be a factor of considerable importance in preventing soil transport.

The Fabricinae are known from the Pacific from comparatively few, mostly isolated, records. The present study concerns some unreported populations from California. In addition, other species of the subfamily from the Pacific are reviewed, and affinities of some others indicated. *Monroika*, a new name, is proposed for *Manayunkia africana* Monro, 1939. There are new combinations in the genera *Fabricia*, *Oridia*, and *Manayunkia*. *Fabricia limnicola* is newly described. The illustrations on the plate were prepared by Mr. Anker Petersen, staff artist of the Allan Hancock Foundation.

The family Sabellidae Malmgren comprises the subfamilies Sabellinae, with 16 to 18 genera and well over 100 species, Fabricinae (below), Myxicolinae, with a single genus and about 7 species, and Lamellisabellinae, an aberrant, controversial category[3] known for a single species, *Lamellisabella zachsi* Uschakow, from the northwest Pacific.

The last named species is known through a single collection from the southern end of the Okhotsk Sea taken at 3,500 meters in gray-green mud (Uschakow, 1933: 205–208, 2 figs.). A more complete description based on some of the same material is that by Johansson (1937: 23–26, 4 figs.) and the most recent discussion is by Ulrich (1950: 1–25). Uschakow regarded the species as an aberrant sabellid and erected for it the subfamily Lamellisabellinae. Johansson made anatomical studies and concluded that the original account mistook dorsal for ventral sides. The originally named ventral collar thus became the head, or prostomium, with the contained central nervous system. The name Pogonofora was proposed for a new class of organism. Ulrich reviewed the previous accounts, and concluded that the species is even more remote from the annelids than previously supposed; he placed Pogonofora between Tentaculata and Enteropneusta.

The available evidence is not yet convincing. Especially noteworthy is the fact that no one has ever seen the mouth. What was presumed to be the brain in the collar lobe may represent a giant suboesophageal ganglion; the true brain and prostomium may lie well concealed by the tentacular crown. In some slender sabellids, these parts are difficult to see unless the tentacular crown is removed or specimens are fixed after removal from the tube.

The major objections to regarding *Lamel-*

[1] Contribution No. 74 of the Allan Hancock Foundation. Manuscript received August 11, 1950.

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[3] A recent communication from Professor J. P. Moore, University of Pennsylvania, Philadelphia, Pa., has expressed a similar view with regard to *Lamellisabella zachsi* Uschakow.

lisabella as a polychaete are the supposed absence of setae (which may, however, be represented by the chitinized platelets); the absence of a dorsal groove (which is present if the collar is ventral); and the scarcity of dissepiments (though this scarcity is known for some other annelids). Strong evidence for Uschakow's view is the high palmate membrane of the crown, the body form, the well-developed thoracic collar, the posterior anus, the segmentally arranged parapodial-like structure, and the uncinial-like structures.

The subfamily Fabricinae Rioja, 1917, includes more than 60 species in 12 or more genera. Unlike members of the Sabellinae, which are often very large and conspicuously colored, the Fabricinae are usually minute (only a few millimeters long), but some of the *Chone* group, such as *Megachone aurantiaca* Johnson, are large (more than 80 millimeters long).

The Fabricinae are remarkable for their adaptability to varying intertidal conditions and their adjustment to either brackish or fresh water. The term "sedentary" is not altogether appropriate since many species construct transitory tubes that are rebuilt after removal. Locomotion is forward or backward. The most nearly related species in such genera as *Fabricia* and *Manayunkia* may have interrupted distributions in widely scattered fresh-water regions and intertidal zones (see below).

In their morphological characters the Fabricinae are sometimes separable only microscopically from some smaller members of the Sabellinae. The most reliable and practical character concerns the structure of thoracic neuropodial hooks: in the Fabricinae they are long-handled (Fig. 3); in the Sabellinae they are avicular, lacking a handle. In the first, the nephridial apertures may open only at the anterior end of the thorax, mid-dorsally near the peristomium (hence the name Thoracogoneata Zenkewitsch, 1925); in the second, the nephridial apertures are present in thorax and abdomen (the Abdominogoneata of Zenkewitsch, 1925). In the Fabricinae, the muscular tissue is nematoid (Johansson, 1927); in the Sabellinae it is not nematoid. In the first there are pulsating pouches (Fig. 1), sometimes called branchial hearts, in the peristomium; in the second such pouches are lacking.

The Fabricinae are recognizable for 12 genera including one (Monroika) newly proposed for an aberrant fresh-water species from the Congo River, Africa (see below). There are other described species, such as *Haplobranchus balticus* Karling, 1933, from Finland, and *Fabricia alata* Ehlers, 1897, from Patagonia, that are not clearly referrable to known genera. These 12 genera, with their Pacific representatives, are as follows:

1. *Caobangia* Giard, 1893, is known for a single small species, *C. billeti* Giard, 1893, from Tonkin, French Indo-China, in fresh water. See Monro (1939: 232) for review.
2. *Chone* Kröyer, 1856, is known for about 20 species, all marine, with the following 6 from the Pacific:
   C. cincta Zachs (1933: 135) from the north Japan Sea.
   C. ecaudata (Moore), 1923, from California. See Hartman (1942: 135–136, figs. e–g).
   C. gracilis Moore (1906: 257–259, figs. 62–66), from Alaska.
   C. infundibuliformis Kröyer, 1856, from Arctic and boreal seas of both hemispheres. See Fauvel (1927: 334–335, fig. 116).
   C. minuta Hartman (1944: 280–281, figs. 50–52, 59–60), from California.
   C. mollis (Bush), 1904, from California. See Hartman (1944: 279–280, figs. 47–49).

   Nine of the remaining species are known from northern and western Europe, two are from the tropical east Atlantic, two are from the Arctic Ocean, one is from northeast America, and one is from South Africa.

3. *Dialychone* Claparède, 1870, is known for a single species, *D. acustica* Claparède, from the Mediterranean Sea. See Fauvel (1927: 333, fig. 115).
4. *Euchone* Malmgren, 1866, is known for about 13 species, all marine, with the following 5 from the Pacific.
   E. alicaudata Moore and Bush (1904: 165–167), from Sagami Bay, Japan.
   E. analis (Kröyer), 1856, from Greenland and the northeast Pacific. See Berkeley and Berkeley (1942: 206).
   E. magna Moore (1923: 245–246), from southern California.
   E. olegi Zachs (1933: 135), from the north Japan Sea. See Annenkova (1938: 215) for review.
   E. papillosa (Sars), 1851, from Finmark and north Japan Sea. See Annenkova (1938: 215).
   In addition, two species are from New England and eastern Canada, one is from Greenland and the north Atlantic Ocean, one is from the British Isles, two are from Spitzberg and Norway, one is from the tropical east Atlantic, and one is from the Kerguelen Islands.
5. *Fabricia* Blainville, 1828, is known for eight or nine species, in brackish to marine seas, with five or six species from the Pacific.
   F. dubia Wesenberg-Lund, 1941, from the northeast Pacific (see below).
   F. limnicola, new species, from California (see below).
   F. pacifica Berkeley and Berkeley, 1950, from western Canada (see below).
   F. ventrilinguata Johansson, 1922, from Japan (see below).
   F. sabella (Ehrenberg), Annenkova (1938: 214) from the north Japan Sea.
   ?F. siaukhu (Annenkova), 1938, from the north Japan Sea (see below).
   In addition, the following species are discussed below: *F. atlantica* (Treadwell), *F. capensis* (Monro), *F. dubia* Wesenberg-Lund, *F. leidyi* Verrill, and *F. alata* Ehlers, which is very questionably a member of this genus.
6. *Jasmineira* Langerhans, 1880, is known for 10 species, all marine, of which one is found in the Pacific.
   J. pacifica Annenkova (1937: 195–196, 3 figs.), from northeast Asia.
   In addition, one comes from Spitzberg, three are from western and southern Europe, two are from the Kerguelen Islands, one is from southwest Africa, one is from Ceylon, and one is from the Antarctic.
7. *Manayunkia* Leidy, 1858, is known for possibly nine species, in fresh water to brackish or marine; one is in the Pacific.
   M. pacifica Annenkova (1934: 329–330, fig. 10), from Bering Island.
   In addition, others from various parts of the world are discussed below.
8. *Megachone* Johnson, 1901, is known for a single marine species, from the Pacific.
   M. aurantiaca Johnson (1901: 430–431, figs. 186–192), from Washington.
9. *Oridia* Rioja, 1917, is known for seven or more species, all marine, of which four are from the Pacific.
   O. armandi (Claparède), 1864, from southern Europe, is reported from western Mexico. See Rioja (1941: 732, pl. 9, figs. 9–10).
   O. crenicollis Annenkova (1934: 330–331, fig. 11), from the Bering Sea.
   O. minuta (Berkeley and Berkeley), new combination (see below).
   O. rivularis Annenkova (1929: 119–122, figs. 1–7), from the Sea of Okhotsk, eastern Asia.
   In addition, another is known from western Europe, one is from Patagonia, and one is from South Africa.
10. *Oriopsis* Caullery and Mesnil, 1896, is known for a single marine species.
    O. metchnikowi Caullery and Mesnil, 1896, from Europe. See Fauvel (1927: 328–330, fig. 114).
11. *Potamethus* Chamberlin, 1919, is known

for five species, all marine, of which two are from the Pacific.

P. elongatus (Treadwell) (1906: 1178, figs. 73–75), from off Molokai Island. See Hartman (1942: 134–135, figs. *b–d*), for emendation.

P. mucronatus (Moore) (1923: 243–245, figs. 43–44), from southern California. See Hartman (1942: 134, figs. *a, b–j*) for review.

In addition, single species come from deep water off Florida and Norway, and from the Antarctic Ocean.

12. *Monroika*, a new name, is proposed for a single aberrant fresh-water species, *M. africana* (Monro), 1939, from the Congo River (see below).

KEY TO GENERA AND PACIFIC SPECIES OF FABRICINAE

1. Thoracic neuropodia with long-handled uncini accompanied by pennoned setae (Hartman, 1942, fig. *i*) ..... *Potamethus* 12
1. Thoracic neuropodia lack pennoned setae 2
2. Tentacular radioles free, without a weblike or palmate membrane 3
2. Tentacular radioles united for some distance by a weblike membrane .. 9
3. First setigerous segment with palmate and slender setae; alimentary tract recurved so that anus is anteroventral; first 7 setigers lack ventral uncini ..... *Caobangia*
3. Palmate setae absent; anus opens posteriorly 4
4. Tentacular radioles vary in length; abdomen with 60 or more segments ..... *Dialychone*
4. Tentacular radioles otherwise; abdomen with few to many segments .. 5
5. Abdomen with many segments; thoracic collar well developed and bilobed ..... *Jasmineira pacifica*
5. Abdomen with few segments or a limited number 6
6. Radioles unbranched ..... *Manayunkia* 13
6. Radioles branched in pinnate arrangement 7
7. With 7 thoracic setigerous segments ..... *Oriopsis*
7. With 8 (except in *Fabricia ventrilinguata*) thoracic setigerous segments 8
8. Abdominal uncini with long handle (Fig. 5); abdomen usually with 3 segments (Fig. 2) .... *Fabricia* 17
8. Abdominal uncini avicular or short handled; abdominal segments 3 to 5 or more ..... *Oridia* 21
9. Abdomen with a deep ventral groove at posterior end of body ..... *Euchone* 25
9. Abdomen without such groove at posterior end of the body 10
10. Tentacular radioles are simple unbranched filaments ..... *Monroika africana*
10. Tentacular radioles have pinnately arranged filaments 11
11. Some thoracic notopodial setae broad and spatulate ..... *Chone* 27
11. Broad spatulate setae absent ..... *Megachone aurantiaca*
12. Thoracic collar oblique; thoracic spatulate setae with a short mucro ..... *Potamethus mucronatus*
12. Thoracic collar nearly straight; thoracic spatulate setae with a long mucro ..... *Potamethus elongatus*
13. With few tentacular radioles 14
13. With many, 16 or more, pairs of tentacular radioles 15
14. With 4 pairs of radioles ..... *Manayunkia estuarina* and *M. polaris*
14. With 6 pairs of radioles ..... *Manayunkia caspica*
15. With 16 to 20 pairs of tentacular radioles 16
15. With 24 to 36 pairs of tentacular radioles ..... *Manayunkia baicalensis*

16. Without peristomial or pygidial eyes ..... *Manayunkia speciosa*
16. With peristomial and pygidial eyes.. *Manayunkia pacifica* and *M. spongicola*

17. Thorax with only 4 setigerous segments..... *Fabricia ventrilinguata*
17. Thorax with 8 setigerous segments.. 18

18. Thoracic collar only ventral and limited; thoracic notosetae include slender and spatulate ones..... 18*a*
    a. Radioles number presumably 2 pairs..... *Fabricia atlantica*
    b. Radioles number 3 pairs..... *Fabricia dubia*
18. Thoracic collar more extensive and with straight margin; thoracic notosetae slender (Fig. 7) to subspatulate..... 19
18. Thoracic collar with festooned fringes ..... *?Fabricia siaukhu*

19. Thoracic collar presumably absent.. ..... *Fabricia leidyi*
19. Thoracic collar present..... 20

20. Collar with a pair of digitate lobes at the middorsum..... *Fabricia capensis*
20. Collar without digitate lobes at the middorsum..... *Fabricia limnicola*

21. Thoracic collar with a crenulate margin..... *Oridia crenicollis*
21. Thoracic collar with a straight margin. 22

22. Pygidial eyes (Fig. 2) present..... 23
22. Pygidial eyes absent..... 24

23. Thoracic setae include spatulate and slender ones..... *Oridia minuta*
23. Thoracic setae include only slender ones..... *Oridia armandi*

24. Thoracic setae include spatulate and slender ones..... *Oridia rivularis*
24. Thoracic setae include only slender ones..... *Oridia limbata*

25. Thoracic spatulate setae lack a mucro ..... *Euchone magna*
25. Thoracic setae with a mucro or slender point..... 26

26. Thoracic collar oblique and longest dorsally..... *Euchone alicaudata*
26. Thoracic collar about equally high all around..... *Euchone analis*

27. Thoracic spatulate setae nearly to without a mucro; body larger, 50 to 100 mm. long..... 28
27. Thoracic spatulate setae with a mucro; body smaller, less than 40 mm. long..... 29

28. Spatulate setae with a short mucro; color in life pale rose or green.... ..... *Chone infundibuliformis*
28. Spatulate setae without a mucro; color in life white or pale yellow..... ..... *Chone mollis*

29. Abdomen with 17 or 18 segments; spatulate setae with a short mucro; radioles number 7 to 9 pairs..... ..... *Chone ecaudata*
29. Abdomen with about 26 segments; spatulate setae with a moderately long mucro; radioles number 6 or 7 pairs..... *Chone minuta*
29. Abdomen with about 51 segments; spatulate setae with a very long mucro; radioles number about 10 pairs..... *Chone gracilis*

Genus FABRICIA Blainville, 1828

This genus was recently re-examined and emended by Berkeley and Berkeley (1950) to include the characters of *Oridia* Rioja (1917). I prefer herein to restrict *Fabricia* to exclude *Oridia*, but to support Berkeley's opinion regarding the lack of importance of thoracic collar development. The diagnosis of the genus is thus the same as that proposed by Berkeley and Berkeley (1950: 66) except that in *Fabricia* the abdominal uncini are long handled and the distal cutting edge has pectinately arranged teeth (Fig. 5), whereas in *Oridia* the abdominal uncini are avicular, lacking a handle.

The generic diagnosis may be summarized. The body consists of the peristomium followed by eight (only four in *F. ventrilinguata* Johansson) thoracic and three abdominal setigerous segments and a pygidium. The

tentacular crown has two or three (Fig. 2) pairs of radioles with filaments in pinnate arrangement; there are no stylodes or radiolar eyes. The palpi are paired and filamentous (Fig. 2). Eyes (Fig. 2) are present in peristomium and pygidium, or one or both pairs are lacking. The thoracic collar is absent, or developed to a varying degree. The first segment lacks setae; the second segment has notosetae only, all of them slender and distally pointed. Segments 3 to 8 (or only 3 to 5) have pointed setae in notopodia; they are slender and narrowly to broadly limbate. Neuropodia have long-handled uncini (Fig. 3). Abdominal segments have pointed setae in neuropodia and long-handled uncini (Fig. 5) in notopodia, with teeth in pectinate arrangement.

The genotype, *F. sabella* (Ehrenberg), has peristomial and pygidial eyes; a thoracic collar is nearly absent; the tentacular crown has three pairs of radioles, and the pinnately arranged filaments are in double rows.

Fabricia limnicola new species

Plate 1, Figs. 1–9

COLLECTIONS: Many individuals come from estuarine, intertidal mud flats of Newport Bay and Anaheim Slough, southern California.

The body is threadlike except for the spreading tentacular crown; total length is 5 to 7 mm. or less; width is ½ mm. or less. Color in life and preserved is pale translucent to white. The body consists of the crown, a simple peristomial ring, eight thoracic and three abdominal setigerous segments, followed by a triangular pygidium.

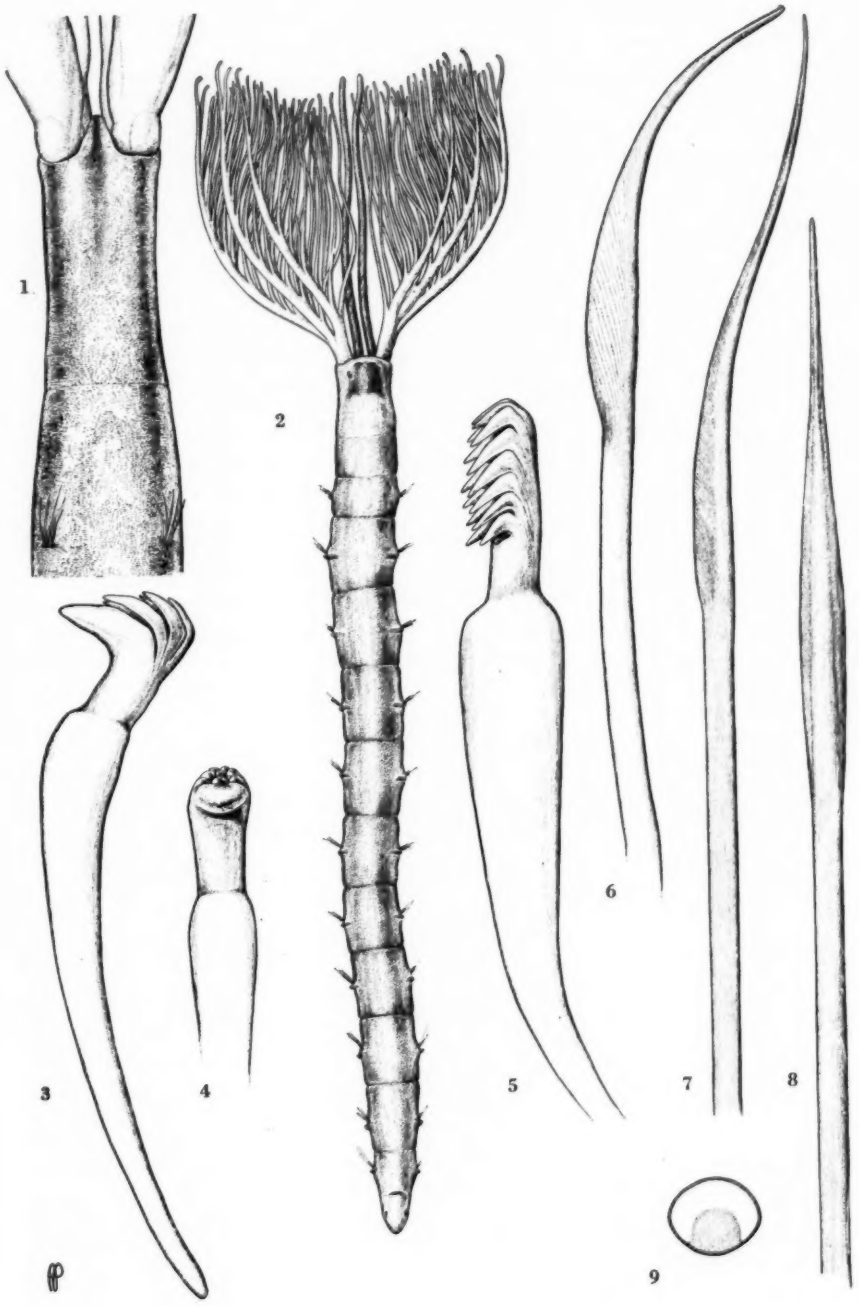
The tentacular crown consists of paired, symmetrical halves with semicircular bases. Each half has three long radioles, lacking a weblike membrane. Each radiole has 6 or 7 to 8 or 10 double rows of slender filaments that rise from the inner lateral side of the radioles; successive filaments rise from different levels but all extend distally about equally far. The total number of filaments for a larger specimen may be 72 to 100. The distal free ends of the radioles are long and smooth (Fig. 2). The paired palpi are long, slender, and dusky in color, and extend distally as far as, or somewhat beyond, the radiolar tips. The prostomium is bluntly rounded to conical; it extends forward so as to be slightly visible beyond the thoracic collar (to be seen when the tentacular crown is removed), or it is less long and fully concealed.

The thoracic collar is a high, straight membrane, continuous all around except for a dorsal fusion with the upper side of the prostomium (Fig. 1); it is closely appressed to the base of the tentacular crown around its lateral and ventral parts and may be overlooked as a separate collar membrane except when the tentacular crown is removed.

The first segment, or peristomium, is longer than those following (Fig. 2); it is longer in specimens fixed in the tube than in those out of it. On its ventral side is a quadrangular, dark area, broadest at its posterior margin; it marks the position of the oral aperture within the collar and is thus between prostomium and peristomium. Dark eyespots are present on the peristomium, visible when the collar is pushed aside.

The second or first setigerous segment is shorter than the peristomium and shorter to longer than those following. It is plain except for the notosetal fascicle which carries from five to eight slender, pointed setae.

PLATE 1. *Fabricia limnicola*. 1, Anterior end showing base of tentacular crown and first two segments, dorsal view, ×66; 2, entire animal with expanded tentacular crown, ventral view, ×37; 3, thoracic neuropodial hook, side view, ×1580; 4, distal end of thoracic neuropodial hook, front view, ×1580; 5, abdominal notopodial hook, side view, ×1705; 6, short thoracic notopodial seta, side view, ×2350; 7, long thoracic notopodial seta, side view, ×1620; 8, long thoracic notopodial seta, back view, ×1620; 9, cross section of thoracic notoseta from widest region, showing core below and expanded region above, ×3240.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Setigerous segments 2 to 8 are biramous. Each notopodium has seven to nine pointed setae and five to eight long-handled uncini arranged in transverse series.

The abdomen consists of three setigerous segments followed by a short, tapering, slightly depressed pygidium, with a pair of dark eyespots located near the posterior end and lateral. The anal aperture is on the ventral side, a short distance in front of the eyes but median. It is followed by a short triangular lobe tapering distally. The proportions and locations of these parts are shown in Figure 2.

Thoracic notosetae are of two kinds. The first three segments have fascicles of eight or nine each; these setae are long, slender, and distally pointed (Figs. 7, 8). Although they appear winged or bilimbate, the distal broad flange is thickened all around the stalk, as can be seen in cross section at the thickest or broadest part of the seta (Fig. 9). Similar setae are present in all other thoracic segments. Beginning at the fourth one and continuing in other thoracic segments, there are only five or six of the longer setae and the lower ones are replaced by three or four shorter, broader ones (Fig. 6). Thoracic uncini are long handled and of a single kind (Fig. 3). They number 7 to 9 or 11 in single transverse series. Each uncinus is slightly beaked and has a large fang and several rows of smaller teeth (Fig. 4).

Abdominal parapodia are biramous. Notopodia are slightly elevated, transversely elongated, and have a single row of handled uncini that number 20 to 30 in a single series; the greatest number in a row is in the first segment and the least in the third segment. The largest uncini in a single series are at the inferior end of the row and there is a gradual diminution in size going upward. These uncini have a double row of seven or eight teeth in pectinate arrangement (Fig. 5). In normal position in parapodia, the tips of the teeth are directed outward and forward. In slide preparations the individual uncini are likely to have handles or teeth imperfect or broken. This fact, together with their small size (less than 20 micra for the length of the distal part beyond the thickened shoulder), doubtless accounts for imperfect or variable descriptions of abdominal uncini in the different descriptions of species in the genus *Fabricia*.

Some of the specimens examined have many small spherical ova, crowded in thoracic setigerous segments 5 to 9. The only color visible in living or preserved individuals is limited to a few regions. There is a dusky area on the ventral side of the collar and peristomium; a similar pigment is on the dorsal side marking the notch of the collar; the prostomial cone and the palpi are dusky; the eyespots in the peristomium and pygidium are dark, and setae are pale yellow.

The tube is constructed of uniformly small, agglutinated sand granules; it adheres closely to the occupant so that specimens fixed in the tube are difficult to remove. In life, removal can be effected by application of a drop of toxic fluid at the end of the tube.

Holotype and other specimens are deposited in the Allan Hancock Foundation of the University of Southern California, Los Angeles, California.

DISTRIBUTION: Southern California, in estuarine marine mud flats.

Fabricia dubia Wesenberg-Lund

Fabricia sabella Berkeley, 1930, fig. 1*g* only.
Fabricia dubia Wesenberg-Lund (1941: 33–35, figs. 2–4).

COLLECTIONS: Many specimens come from South Bay in Coos Bay, Oregon, washed from intertidal rocks, August, 1950 (coll. Donald Reish).

Individuals measure 2 to 3 mm. long and 0.26 mm. across. There are eight thoracic and three abdominal setigerous segments; the last five thoracic segments are much the longest. The tentacular crown consists of three pairs of radioles, each having many paired filaments in bipectinate arrangement. The paired palpi are triangular and extend

only slightly beyond the ventral collar lobe. Eyes consist of a conspicuous pair of dark spots at the sides of the peristomial region and another similar pair at the sides of the pygidial lobe.

Thoracic notosetae are of two kinds; the upper are longer than the abruptly shorter lower ones; all have a terminal mucro that is longer than that shown by Wesenberg-Lund (1941, fig. 4).

The thoracic collar is obscure except for a large midventral lobe that extends across the ventrum; it is shown by Berkeley (1930, fig. 1*g*) and Wesenberg-Lund (1941, fig. 2). The body is pale yellow and has a dusky, semicircular crescent of dark pigment, open in back, across the ventrum of the thorax. The anal aperture is dorsal, located in the pygidial lobe in front of the eyespots. Tubes are cylindrical, have a translucent, chitinized base, and are loosely covered with small sand grains attached on edge or broadside.

Fabricia dubia Wesenberg-Lund was first described from the harbor of Copenhagen, Denmark, among barnacle growths. In my opinion, *F. sabella* Berkeley (1930, fig. 1*g* only), from stones at Newcastle Island, western Canada, is identical. *F. atlantica* (Treadwell) (1932) from New Brunswick, eastern Canada, is very similar except for the radiolar stalks, which are said to number only two pairs; in other respects it appears to be identical.

DISTRIBUTION: Eastern Denmark; Oregon and western Canada.

Other species of *Fabricia* from the Pacific are as follows:

1. **F. pacifica** Berkeley and Berkeley (1950: 66–67), from western Canada, taken at low tide, was earlier described as *F. sabella* Berkeley (1930: 73, 3 figs.). The thoracic collar is high and well defined; it is deeply incised on the dorsal side; peristomial and pygidial eyespots are present; abdominal uncini are long handled and have six or seven teeth, presumably in a single pectinate row.

2. **F. ventrilinguata** Johansson (1922: 9, pl. 4, figs. 1–3) is a marine species from Japan. It has only four, instead of eight, thoracic setigerous segments; the abdominal count is not known. Presumably, eyes are absent. There are three pairs of radioles that lack a weblike membrane. Abdominal uncini are handled and have teeth in pectinate series. The generic status may be doubtful because of its low segmental count.

3. **F. sabella** (Ehrenberg), 1836, originally from western Europe, is recorded by Annenkova (1938: 214) from the north Japan Sea, among corallines, without description.

4. ***?F. siaukhu*** (Annenkova), new combination, was originally described as *Manayunkia siaukhu* Annenkova (1938: 214, 230) from north Japan, among algae. This has tentacular radioles with pinnately arranged filaments and is thus not a species of *Manayunkia* Leidy. A thoracic collar is present; it has festooned margins and is deeply notched dorsally. The tentacular crown has three pairs of radioles; each radiole has a long slender tip and the many fine filaments end at about the same level. There are eight thoracic and three abdominal setigerous segments; the peristomium is a smooth ring. Eyes include two in the peristomium and one in the pygidium. These characters agree with those of *Fabricia*. The generic status is questionable because abdominal uncini remain unknown.

In addition, the following species belong to the genus *Fabricia* Blainville:

1. ***F. capensis*** (Monro), new combination, was originally described as *Oridia capensis* Monro (1937: 366–370, figs. 1–8), from South Africa. There are eight thoracic and three abdominal setigerous segments. The body is about 10 mm. long and 0.3 mm. wide, and the tubes measure 50 to 60 mm. long. The tentacular crown has three pairs of radioles, each with seven or eight filaments in (presumably) a single row. The peristomial collar is entire except for a pair of digitate lobes at the middorsum. Eyes include one pair in the peristomial ring and one pair in the pygidium. Thoracic notosetae are slender,

the neurosetae are long-handled uncini. Abdominal unicini are handled, with teeth in a pectinate row.

2. ***F. atlantica*** (Treadwell), new combination, was originally described as *Haplobranchus atlanticus* Treadwell (1932: 279–280, figs. 1–8) from St. Andrews, New Brunswick, in intertidal mud tubes. There are eight thoracic and three abdominal setigerous segments. The body measures about 4 mm. long. The thoracic collar is prominent on the ventral side and oblique at the sides; the dorsal end is short. The tentacular crown is incompletely known, except that it has pinnately divided radioles, each with a double row of seven or eight filaments. There are paired eyes in the peristomium and in the pygidium. Thoracic uncini are long handled; abdominal uncini are moderately long handled and have teeth in pectinate series. The second to eighth segments have slender and subspatulate setae in notopodia.

3. **F. leidyi** Verrill (1873:619), from New England, was not described until later by Leidy (1883: 210–211, figs. 14–20), based on specimens from Massachusetts and Rhode Island, found on rocks between tide marks and under patches of *Fucus*. The tubes project from the sand and mud and are firmly fixed together. Individual specimens measure 3 to 4 mm. long; color in life is yellowish brown. The thorax consists of eight and the abdomen of three setigerous segments. There are paired eyespots in the thorax and in the pygidium. The tentacular crown consists of three pairs of pinnately branched radioles with the filaments in a double row. The thorax has slender and spatulate notosetae and long-handled uncini. The abdomen has long-handled uncini above and slender setae below. A collar is not known to be present. In this respect, the species compares with the genotype, *F. sabella* (Ehrenberg). Except for the presence of spatulate thoracic setae, reportedly absent in *F. sabella*, the two are not clearly separable. Wesenberg-Lund (1941: 36) suspects the presence of spatulate setae even in the genotype and thinks they may have been overlooked.

4. **?F. alata** Ehlers (1897:135–137, figs. 206–210), from Patagonia and South Georgia in littoral zones, is questionably a species in this genus. An emended account, based on Antarctic collections, is in preparation.

Genus MANAYUNKIA Leidy, 1858

Leidy (1883: 204–211, pl. 9, figs. 1–24) gives an emended account.

The type species is *M. speciosa* Leidy, 1858.

Manayunkia includes *Haplobranchus* Bourne, 1883, *Dybowscella* Nusbaum, 1901, *Garjaiewella* Dybowski, 1929, *Fabriciella* Zenkewitsch, 1935, and *Fabriciola* Friedrich, 1940.

The tentacular crown has bases that are semicircular; radioles are simple, unbranched filaments that range in number from 16 to 36 down to only 4 pairs; they rise from a common base and are not pinnatedly arranged, thus differing sharply from *Fabricia* (above). There is no weblike or palmate membrane at the base of the crown. The peristomium lacks or has a collar that is entire or has a dorsal notch. Eyes are absent, or present as a pair in the peristomium or also pygidium. The body includes eight thoracic and three abdominal setigerous segments. The peristomium lacks setae. The setal formula agrees with that of *Fabricia* (see above).

Fabriciella Zenkewitsch (1935: 199) was proposed to include two species, *Manayunkia pacifica* Annenkova and *Fabricia* (*Manayunkia*) *spongicola* Southern, both of which are here retained in *Manayunkia* Leidy. *Fabriciella* was distinguished from *Manayunkia* Leidy mainly for having pygidial eyespots and for specific differences in the tentacular crown, both of which characteristics are given only specific distinction in the present account. For the same reason, *Fabriciola* Friedrich (1940: 362) is here regarded congeneric.

Only one species is known from the Pacific.

1. **Manayunkia pacifica** Annenkova (1934: 329–330, fig. 10) comes from the

Bering Sea in littoral zones. The body is minute, only 1.5 to 3 mm. long, and is cylindrical in shape. There are eight thoracic and three abdominal setigerous segments. The tentacular radioles number 15 to 18 on a side, are slender, unbranched, and arranged in a tuft. There is no palmate membrane, and all radioles are about equally long. The palpi are long. The thoracic collar is a simple undivided flange incised only on the dorsal side. There are paired eyes in the peristomium and in the pygidium. The setae and uncini are those characteristic of the genus. The tube is of silt and fine sand.

In addition, the following species appear to be congeneric:

1. *M. aestuarina* (Bourne), 1893, from western Europe in fresh water. (See Fauvel 1927: 326–327, fig. 113.)

2. *M. baicalensis* (Nusbaum), 1901, from Lake Baikal, in fresh water. (See Zenkewitsch, 1925: 34–35, figs. A to X.)

3. *M. caspica* Annenkova (1928: 19–20, pl. 3, figs. 1–4), from the Caspian Sea in 44–64 meters.

4. *M. polaris* Zenkewitsch (1935: 195–203, figs. 1–6), from northwest Russia at midtide level. This appears to be near *M. aestuarina* (Bourne).

5. *M. speciosa* Leidy, 1858 (see Leidy, 1883: 204–211, pl. 9, figs. 1–24), from northeast United States in fresh and brackish water, and recorded also from the western end of Lake Superior by Meehearn (1929: 479–480). *M. eriensis* Krecker (1939: 153) from Lake Erie, Ohio, in fresh water, may be the same.

6. *M. spongicola* was originally named *Fabricia* (*Manayunkia*) *spongicola* Southern (1921: 653–655, pl. 31, fig. 29) from Lake Chilka, India, in fresh water.

7. *M. baltica* (Friedrich) (1940: 363–364, figs. 1–2) from the Baltic Sea.

8. *M. bochmanni* (Friedrich) (1940: 364–365, figs. 3–4) from the Baltic Sea.

Other species that were originally described as *Manayunkia*, or under one of its synonyms, are the following:

1. *Haplobranchus balticus* Karling (1933: 242–245, figs. *a–e*), from the Baltic Sea, has unbranched radiolar filaments as in *Manayunkia* Leidy. However, there are 11 thoracic and 3 abdominal setigerous segments. The first segment has both setae and uncini. These characters do not agree with any named genus.

2. *Manayunkia africana* Monro, 1939, is here referred to *Monroika* (see below).

3. *Manayunkia siaukhu* Annenkova, 1938, is questionably referred to *Fabricia* (see above).

4. *Haplobranchus atlanticus* Treadwell, 1932, is referred to *Fabricia* (see above).

Genus ***Monroika*** new name

The small body, a few millimeters long, consists of a simple peristomium, eight thoracic and two abdominal setigerous segments. The tentacular crown has simple, undivided radioles in a tuft, as in *Manayunkia*, but there is a high weblike palmate membrane that unites the bases of the radioles. The thoracic collar is distinct and entire with a middorsal incision. Eyespots are lacking from the peristomium and pygidium. The first segment lacks setae. The first setigerous segment has notosetae only. The second to fifth have slender and spatulate notosetae and long-handled uncini. Segments 6 to 8 are similar but lack spatulate notosetae. Abdominal segments have handled uncini with teeth in pectinate rows; neurosetae are slender. *Monroika* differs from *Manayunkia* especially in having a weblike membrane in the crown. A single species is known.

Monroika africana (Monro) is the type species.

Monroika africana (Monro) new combination

Manayunkia africana Monro (1939: 220–223, figs. 1–5).

Length of the body is about 2 mm. The weblike tentacular membrane extends distally for about a third of the radiolar length. Radioles number about 12. The species is known only from the Congo River, about

150 km. from the sea and beyond tidal effects; it occupies sandy tubes on mollusk shells and in incrustations on stones.

Genus ORIDIA Rioja, 1917

This genus differs from *Fabricia* Blainville essentially in having abdominal uncini that lack a handle. There are 8 thoracic and 3 to 12 abdominal setigerous segments. Tentacular radioles number two to five pairs and have filaments in pinnate arrangement. A thoracic collar is present or absent. Peristomial and pygidial eyespots are present. Thoracic uncini resemble those of *Fabricia*. Four species are recorded from the Pacific (see above). One is here newly referred to *Oridia*.

Oridia armandi (Claparède), 1864, is the type species.

Oridia minuta (Berkeley and Berkeley) new combination

Fabricia minuta Berkeley and Berkeley (1932: 315–316, figs. A–E).

Total length is about 11 mm. and width is about 0.1 mm. The body consists of eight thoracic and three to five abdominal setigerous segments. The tentacular crown consists of two pairs of radioles with pinnately arranged filaments. A thoracic collar is lacking. Peristomial and pygidial eyespots are present. Thoracic notosetae are slender and subspatulate. Thoracic uncini are sharply curved; abdominal uncini lack a stem.

This species is known only from the west coast of Vancouver Island, Canada, from among algae.

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The Ecology of the Mosquito Larvae of New Guinea

GEORGE H. BICK[1]

INTRODUCTION

FROM SEPTEMBER 1943 to January 1945 I was in New Guinea as Officer in Charge, U. S. Navy Malaria Control Team 25, and was stationed at Milne Bay, Morobe, Finschhafen, and Saidor. The entire period was spent in almost daily field collecting of larval mosquitoes. During the same period Dr. George H. Penn was stationed at Milne Bay, Amsterdam Island, and Woendi Island as Officer in Charge, U. S. Navy Malaria Control Team 28. Before arriving in New Guinea we agreed to combine all collections and to record all habitat data on standard collection cards.

This study is based on an analysis of the habitats utilized by 47 species of mosquitoes present in a total of 1,508 collections. The habitat records presented here are not the results of opinions on habitat relationships; they are numerical analyses of all collection data.

Comprehensive studies of the ecology of the mosquito larvae of New Guinea are completely lacking. There are numerous scattered notes on habitat, especially for the more recently described species, and there are more detailed ecological studies of certain of the medically important species. But there is no broad ecological survey summarizing the habitat relationships of all common species of this area.

Some of the more important taxonomic works in which ecological notes may be found are those of Taylor (1914–1943), Hill (1925), Bonne-Wepster and Brug (1932, 1937, 1939), Lee (1944*a*, 1946), Lee and Woodhill (1944), King and Hoogstraal (1946–1947), and Marks (1947). Recently more detailed habitat studies of individual species of medical importance have been recorded by Horsfall and Porter (1947), Forbes and Horsfall (1947), and Penn (1947*a*).

Acknowledgments. Many persons have assisted in this study. I wish to thank Professor Robert Matheson, Cornell University, for his friendly encouragement and counsel. Dr. George H. Penn, Tulane University, assisted in developing the collecting technique, and made many of the collections. My appreciation is extended to the men of Malaria Control Teams 25 and 28 (W. W. Bonds, H. W. Dorman, A. S. Griswold, J. E. Surgenor, W. T. Whitfield, P. B. Tompkins, O. L. Andrews, A. C. Bodenman, W. L. Schmid, R. E. Geiger, J. P. Gallagher, and M. A. Greenblatt) by whose efforts many collections were made, often under trying field conditions. Professor F. A. Perkins, University of Queensland, extended every courtesy, including the full facilities of his Department, and Miss Elizabeth Marks of the same institution identified many specimens and supplied important literature aids. Dr. Alan Stone, U. S. National Museum, clarified many of the taxonomic problems. Dr. W. M. Rogoff and Dr. A. G. Humes supplied species lists to add to the distribution data.

LOCALITIES STUDIED

All collections were made within, or just adjacent to, military bases which in every case were situated along the North Coast. In general, these bases were built on strips of land lying between the ocean and the mountains, and varying in width from about a quarter of a mile to 5 miles. However, Woendi and Amsterdam were small coral islands.

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The most conspicuous feature of all areas was the ubiquitous coconut plantation. In most instances, puddles and artificial containers were common, whereas ponds, lakes, and marshes were nearly always absent. New habitats developed rapidly. The most outstanding of these were puddles and artificial containers. Moreover, each area was under intensive military control and, in several, thorough initial surveys were delayed because of enemy interference.

The above factors undoubtedly influenced the data. However, since each area was bordered by an accessible fringe roughly representative of natural conditions, and since collections were from both base periphery and from the more artificial base site, it is believed that significant data on the *habitat potentials* of the various species have been obtained.

The collecting areas and dates are:

Milne Bay, Papua (10° 20′ S/150° 30′ E).
- Gamadodo: September 1943 through March 1944; September through November 1944.
- Wagga Wagga: October through November 1944.
- Hilimoi: August through November 1944.
- Kana Kopa: October 1943 through January 1944; September through November 1944.

Morobe, Northeast New Guinea (7° 45′ S/147° 35′ E): November 1943.

Finschhafen, Northeast New Guinea (6° 35′ S/147° 50′ E): January through June 1944.

Saidor, Northeast New Guinea (5° 40′ S/146° 30′ E): February through June 1944.

Woendi, Padaido Islands, Dutch New Guinea (1° 15′ S/136° 20′ E): July through October 1944.

Amsterdam Island, Dutch New Guinea (0° 20′ S/132° 10′ E): August through October 1944.

METEOROLOGICAL DATA

The only data available were those of the temporary Navy Station at Milne Bay and the Australian Station at Samarai. Rainfall and temperature records for 1943 and 1944 were obtained from the Navy, and the long-time averages from Samarai. Since the majority of collections were from Milne Bay, data from these sources are indicative of conditions under which most of the collections were obtained.

Figure 1 compares the 29-year average monthly rainfall with that for the collecting period. It also compares the 9-year average monthly maximum, mean, and minimum temperatures with those for the collecting period.

The 29-year average rainfall shows no great monthly variation. Rainfall during the collecting period paralleled the long-time average, except during April and June 1944, when brief torrential rains increased the amount to far above the average. No collections were obtained from Milne Bay during these months. These data demonstrate an absence of definite wet and dry seasons. This is in marked contrast to the much-discussed wet and dry seasons which have played such an important role in mosquito bionomics in other tropical areas, notably the Solomon Islands and the New Hebrides. Similarly, temperature data show but slight seasonal variation.

No seasonal fluctuation in numbers of species or numbers of individuals of mosquito larvae was observed. It is concluded that neither rainfall nor temperature was a factor limiting the mosquito population during any season of the year.

METHODS

Distribution

Data were obtained from: (1) literature records; (2) collections from the detail-study areas; (3) unpublished records of A. H. Humes, W. M. Rogoff, and T. K. Ruebush, who were in New Guinea during periods corresponding to these collections.

All records available in the literature on New Guinea are listed for each of the 47

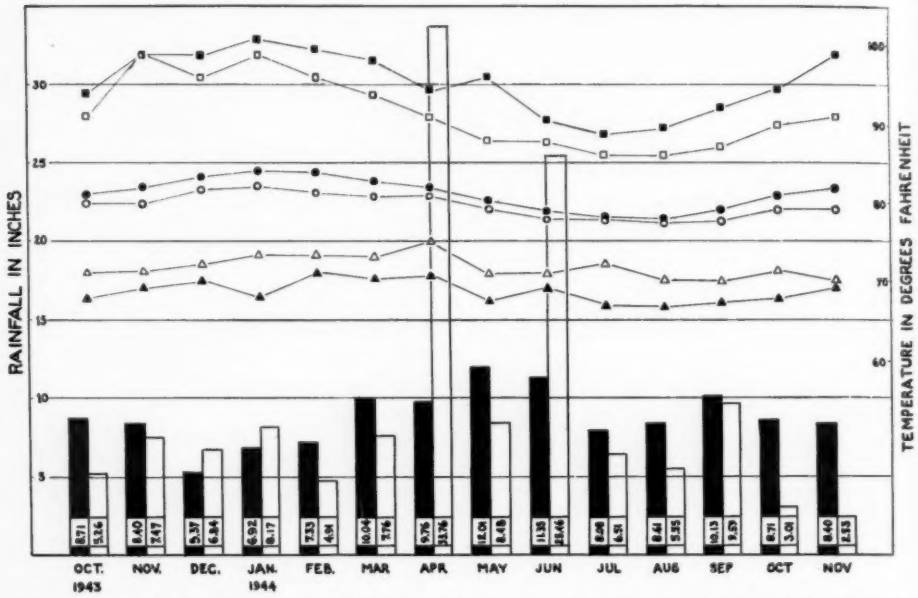

FIG. 1. Monthly temperature and rainfall during collecting period at Milne Bay (open symbols and blocks) compared with the long-time average for the Samarai weather station (solid symbols and blocks). Long-time average figures were obtained through courtesy of Directorate, Meteorological Services, RAAF, Melbourne.

species[2] collected in the areas of study. When the same locality is repeated by several authors, each reference is included. All type localities in New Guinea are given, but additional references to this locality are not repeated. Latitude and longitude for nearly every locality may be found in the U. S. Army Map Service *Gazetteer to Maps of New Guinea* (1943).

A great variety of spellings of the various place names was encountered. Moreover, many of the German names employed in Northeast New Guinea were changed after the area became an Australian mandate. To avoid confusion, all spellings used in this report are those given in the Army's *Gazetteer*.

Collecting Technique

Each collection was a sample from a particular microhabitat at a particular time. Each microhabitat usually presented at least one distinguishing characteristic, even when several of them were located in temporary water in close proximity. A single macrohabitat often included a large number of microhabitats in a very limited horizontal range. For example, in certain cases the superficial picture may have been of a definite marsh, yet separate collections could be made from puddles, artificial containers, coconut shells, etc., through a great range of microhabitats. As a result of sanitary control operations, repeat collections from the same microhabitat were seldom possible.

All ecological data were recorded in the field, using for each collection a 3×5 index card whereon space was provided in the center for recording the locality, date, time, and

[2] In the thesis on which this paper is based (deposited in the library of Cornell University) I have listed all distribution records of the 179 species ever recorded from New Guinea as well as my own distribution records for the 47 species discussed in this paper. In addition, all literature on the ecology of the larvae of each of the 179 species was summarized and compared with my own numerical data. However, for the sake of brevity, this paper deals primarily with distribution and ecological data for the 47 species I personally encountered.

collector's initials. Ecological terms were listed around the margins so the collector simply checked the appropriate blocks. This method reduced the possibility of omitting important data from field notes compiled at random. A similar card punch system is discussed by Boyd (1930).

Identifications

For most collections, a representative series of individuals was reared in isolation. Identifications in nearly every case were based on reared material. The majority of these reared adults were checked by Dr. Alan Stone of the U. S. National Museum, and others were checked by Miss Elizabeth Marks of the University of Queensland. Most of the specimens have been deposited in the U. S. National Museum, and representative series of associated larvae, pupae, and adults have been placed in the collections of Cornell University and the University of Queensland, Brisbane, Australia.

ANALYSIS OF DATA

Habitats

After all recorded data on the ecology of the larvae were assembled, it became obvious that the literature was markedly deficient in quantitative data. Scarcely a reference presents numerical data which show the actual degree of utilization of a habitat. Some authors use such terms as "sometimes," "rarely," "frequently," but most merely list all habitats without qualification, so that it is impossible to distinguish the usual from the unusual. Undoubtedly, many authors unduly stress rare habitats. It seems that single collections from such breeding places are so repeated in the literature that gradually the focus is concentrated on the rare to the point of neglecting the really important—the usual.

Therefore, I believe that only a numerical presentation of data can furnish both a brief and an accurate basis for determining habitat potentials, and only the use of numbers will permit a comparison of the results of different studies.

Larval habitats have been variously recorded by nearly every author who has attempted to summarize an extensive number of collections. The majority simply give the range of habitats applicable to the particular area, listing every specific habitat, such as "K ration box floating in a river." Such details are meaningless when data are compared. Moreover, even though some authors attempt to classify habitats, their descriptive terms are unique. Thus, comparison of data is almost impossible. Obviously there is need for a classification of habitats using very broad terms that are universally applicable.

Shannon (1931) proposed a very general classification dividing all habitats into two major categories: (1) depressions in the ground, and (2) water in containers above ground. He subdivided each of these into natural and artificial water. Bonne-Wepster and Brug (1932) found the following adequate for their investigation of *Stegomyia* in the Dutch East Indies: (1) earth-bound habitats, (2) vegetable breeding places, (3) man-made containers. Bates (1949) divided larval habitats into four major groups: (1) permanent or semipermanent standing water, (2) running water, (3) transient ground pools, (4) container habitats. Arnett (1950) summarized the habitats recognized in Panama as follows: (1) surface water, (2) aerial habitats, (3) artificial containers.

I believe that general use of such major categories by all workers, supported by numerical data, would quickly give an adequate picture of the habitat potentials of the various species. Such a picture could then be utilized as the basis of sound control procedures.

My organization of larval habitats corresponds to that of Bonne-Wepster and Brug and of Shannon. They were grouped into three major divisions: (1) fresh surface water, both natural and artificial, (2) fresh water in containers, both natural and artificial, (3) brackish or salt water. These were further divided into a rather large number of

more specific microhabitats, which are listed in Table 2.

The term "habitat index" is used as a convenient way of referring to the ratio between the number of collections of a species in a particular habitat and the total number of collections of that species.

Habitat Factors

An extensive literature has accumulated in an attempt to determine the effect of chemical and physical factors on the breeding habits of various species. Many factors have been investigated, but specific conclusions concerning the role of any one factor as an absolute indicator of potential breeding are almost entirely wanting.

A comprehensive quantitative study of the physio-chemical factors such as light intensity, dissolved oxygen, etc., was impossible under our field conditions. Our aim was to describe the general character of the habitat by careful observations using quantitative determinations when possible. Therefore only major factors such as exposure, superficial character of the water, vegetation, *p*H, were considered. In this report the habitat factor is given as the percentage of our collections in which that factor was recorded.

It should be noted that stagnant water was always static, with varying amounts of organic debris in the early stages of decomposition. In polluted water, decomposition was always well advanced and produced a foul smell. *p*H was determined in the field for many but not for all collections, using Squibb's nitrazene paper (range 4.5–8.0). Salinity was measured with a hydrometer in all cases of suspected brackish water and was considered experimentally for *An. punctulatus* and for *An. farauti*.

Species Association

The most common method of presenting numerical data indicating the degree of association is in the form of a table showing the actual number of times any two species were found together in individual collections. However, Hacker (1921) proposed the "Association Unit" and Dice (1945) the "Association Index" as measures of the degree of association between species. A combination of the methods of Hacker and Dice was used in determining my association indices.

Collections of any one species were either pure or in various combinations with one or more additional species of mosquito larvae. The value (P) of pure collections for any one species (A) is the ratio between the number of times the species was collected alone and the total collections of species A. Then a measure of the value of mixed collections (M) can be taken as 100-P. Each cohabitant is assigned a relative portion of this total as follows: hM/t, where h equals the number of times species A was found with any other species and t equals the number of times species A was found with all cohabitants. In this paper, species having an association of less than 4 per cent have been grouped and given as "others."

Bironella

Because of the confusing status of various species in the genus *Bironella*, it was impossible accurately to determine species of this genus during the collecting period. Laboratory rearing was so difficult that only five adults were available for checking: two specimens from Milne Bay were identified by Dr. Stone as *B. travestitus* and three from the same locality as *B. soesiloi* sensu Swellengrebel and Rodenwaldt. Because of the rather limited literature on the biology of *Bironella* it is considered worth while to present these data even though more than one species is represented.

DISTRIBUTION: *Bironella* species were present in collections from Milne Bay, Morobe, Finschhafen, and Saidor. Collections were nowhere numerous and the number of individuals in each collection was always rather limited. It seems that *Bironella* species would have been represented more abundantly if extensive collecting had been possible from

the headwaters or at least from the higher reaches of the mountain streams.

HABITAT:

Total collections, 34

Habitat	*Number of collections*	*Habitat index*
Creeks: Pot holes	19	56
Creeks: Running	14	41
Rock holes	1	3

*p*H, 11 readings

Range	4.0–6.5
Mode	5.0
Average	5.1

Factor	*Percentage occurrence*
Shaded	76
Exposed	24
Temporary	3
Semi-permanent	56
Permanent	41
Clear	100
Vegetation	
Absent	56
Present	44
Sparse	30
Moderate	47
Abundant	23
Algae	17
Emergent	17
Overhanging	50
Submerged	11
Floating	5

The genus *Bironella* occurred mostly (68 per cent) in pure collections. Percentages of associates were: *U. argyrotarsis*, 11; *C. fraudatrix*, 9; *C. pullus*, 4; others, 8.

Bironella (Bironella) soesiloi sensu Swellengrebel and Rodenwaldt

"*B. papuae* No. 22147 (B. soesiloi Strickland)" Soesilo and van Slooten, 1931, Geneesk. Tijdschr. Nederland. Indië 71: 126.

Anopheles papuae soesiloi Strickland (Bei Soesilo and van Slooten, 1931) Swellengrebel and Rodenwaldt (1932: 62).

DISTRIBUTION: Dutch New Guinea: Boemi-Bezirk, Hollandia (Swellengrebel and Rodenwaldt, 1932). Lee and Woodhill record it as questionable from Boemi and Hollandia. Papua: Milne Bay (Lee and Woodhill, 1944; Author).

HABITAT: Lee and Woodhill (1944) record it from a swampy creek. Both of my collections were from pot holes in creeks, in fresh, temporary, clear, shaded water at a *p*H of 5. It was found once in a pure collection and once with *U. argyrotarsis*, *C. papuensis*, and *B. travestitus*.

Bironella (Brugella) travestitus (Brug)

Anopheles (*Bironella*) *travestitus* Brug, 1928, Geneesk. Tijdschr. Nederland. Indië 68: 921.

DISTRIBUTION: Dutch New Guinea: Tahahmerah (Swellengrebel and Rodenwaldt, 1932). Papua: Cape Endaiadere (Lee and Woodhill, 1944); Milne Bay (Lee and Woodhill, 1944; Author).

HABITAT: Lee and Woodhill record it in partially shaded swamps and in pools in a sago swamp. My single collection was from a temporary, shaded pot hole in a creek, with a sparse amount of debris, at a *p*H of 5, and in association with *U. argyrotarsis*, *C. fragilis*, and *B. soesiloi* sensu Swellengrebel and Rodenwaldt.

Anopheles (Anopheles) bancrofti pseudobarbirostris Ludlow

Anopheles pseudobarbirostris Ludlow, 1902, N. Y. Ent. Soc. Jour. 10: 129.

DISTRIBUTION: Northeast New Guinea: Sepik River, Madang (Lee and Woodhill, 1944); Saidor (Author). Papua: Cape Endaidere, Oro Bay, Terapo, Lalapipi, Dobodura (Lee and Woodhill, 1944); Milne Bay (Lee and Woodhill, 1944).

HABITAT: Lee and Woodhill state that it is found only in the jungle, usually in clear pools with abundant aquatic vegetation, in dense shade, or in places which receive direct sunlight only during the middle of the day.

In our survey, *pseudobarbirostris* was present in three collections from ponds with vegetation. Its scarcity may be due to the fact that its chief habitat seems to be rather large, permanent, well-vegetated bodies of clear, shaded water which were almost entirely ab-

sent in the study areas. It was collected with *An. punctulatus*, *An. farauti*, *U. argyrotarsis*, and *C. fraudatrix*.

Anopheles (Myzomyia) farauti Laveran

Anopheles farauti Laveran, 1902, Soc. de Biol. [Paris] Compt. Rend. 54: 908.

Anopheles punctulatus molluccensis Sw. and Sw. de Graaf. Lee and Woodhill (1944: 140).

Anopheles punctulatus farauti Laveran. Mackerras and Aberdeen (1946: 770); Mackerras (1947: 1–8).

In 1945 Owen described *An. koliensis* from the Solomons. This form is intermediate between *An. punctulatus* and *farauti*. Certain earlier workers have long recognized "intermediates" which are clearly *koliensis;* others make no distinction. Obviously, in the latter cases the material cannot be safely referred to any of the three species (or subspecies) of the complex. I have limited the literature in the following discussions to those who, apparently, were clearly aware of *koliensis* or at least of intermediate forms. I believe that most of my material is *farauti* but, since all of the collections were made without knowledge of *koliensis* and since only a relatively few individuals were available for subsequent careful checking, certainty is impossible.

DISTRIBUTION: Dutch New Guinea: Batavia-bivak, Motorbivak, Kokas, Kaimana, Fakfak, Prauwenbivak, Tanahmerah, Sorong, Meervlakte, Salawati, Biak Island, Japen Island, Aru Island (Lee and Woodhill, 1944); Hollandia (Lee and Woodhill, 1944; Rozeboom and Knight, 1946); Merauke (Lee and Woodhill, 1944; Mackerras, 1947); Padaido Islands, Amsterdam Island (Author). Northeast New Guinea: Lae, Salamaua (Lee and Woodhill, 1944); Ramu Valley (Mackerras, 1947); Wewak (Mackerras and Aberdeen, 1946; Mackerras, 1947); Finschhafen, Saidor (Author). Papua: Samarai, Port Moresby, Koitaki, Oro Bay, Dobodura (Lee and Woodhill, 1944); Lalapipi (Lee and Woodhill, 1944; Mackerras, 1947); Bulldog, and near mouth of Lakekamu River (Horsfall and Porter, 1947); Milne Bay (Lee and Woodhill, 1944; Mackerras, 1947; Author).

HABITAT:

Total collections, 170

Habitat	*Number of collections*	*Habitat index*
Puddles	89	52
Creeks: Running	26	15
Creeks: Pot holes	23	14
Swamps	9	5
Borrow pits	8	5
Ditches	5	3
Ponds	3	2
Marshes	2	1
Coral pools	2	1
Artificial containers	2	1
Rock holes	1	0

*p*H, 67 readings

Range	4.0–8.0
Mode	5.0
Average	5.7

Factor	*Percentage occurrence*
Shaded	25
Exposed	75
Temporary	55
Semi-permanent	21
Permanent	24
Clear	66
Muddy	17
Stagnant	15
Polluted	2
Vegetation	
Absent	39
Present	61
Sparse	30
Moderate	43
Abundant	27
Algae	42
Emergent	25
Overhanging	16
Submerged	10
Floating	7

In the New Hebrides and Solomon Islands, Belkin *et al.* (1945), Perry (1946), and Daggy (1945) found that the breeding places consisted primarily of relatively large collections of surface water, but that after heavy rains a great variety of small temporary water collections was used. In New Guinea, Lee and Woodhill (1944) considered sago swamps, backwaters of creeks, and grassy pools and puddles as common habitats. Horsfall and Porter (1947) also give natural pools and

grassy margins of streams as most frequently used sites. Nearly all of these recorded habitats are represented in my collections. However, *farauti* was collected almost entirely (99 per cent) in surface water; the only other habitat represented was artificial containers. The range of surface habitats was rather wide but these data clearly show the great relative importance of puddles.

All workers in the New Hebrides-Solomons area have emphasized the contrast in utilization of wet- and dry-season breeding sites. No such contrast was apparent from my observations nor has such been reported by other workers in New Guinea.

Seventy-five per cent of my collections were made in exposed situations. All authors state that *farauti* occurs both in sun and shade; however, Belkin *et al.* (1945), Daggy (1945), Perry (1946), and Horsfall and Porter (1947) give a preference for sunlight, whereas Lee and Woodhill (1944) give a preference for semi-shade.

Vegetation was present in 61 per cent of my collections. Lee and Woodhill (1944), Belkin *et al.* (1945), Perry (1946), and Horsfall and Porter (1947) consider the presence of vegetation or floatage of prime importance in the ecology of *farauti*.

Only 17 per cent of my *farauti* collections were taken from muddy water, whereas 32 per cent of the *punctulatus* collections were from muddy water. This difference was emphasized by Lee and Woodhill (1944), who stated that *farauti* is rarely recorded in man-made pools with a heavy suspension of clay but that such pools serve as the typical breeding place of *punctulatus*. Horsfall and Porter (1947), on the basis of quantitative data, concluded that *farauti* is dominant in sandy or mucky soil whereas *punctulatus* is dominant in heavy clay.

Nothing on *p*H relationships has been reported. My 67 readings from nearly all habitats show a very wide range (4.0 to 8.0). However, both the mode and the average were approximately 5.5.

Lee and Woodhill (1944) record *farauti* at a salinity of 1.4 per cent at Goodenough Island. Perry (1946), in the New Hebrides-Solomons area, found it common in water containing less than 70 per cent sea water, and stated that its upper maximum level was 75 per cent sea water. From a total of 170 collections in strictly coastal localities, only four were taken in brackish water on Amsterdam Island. Two were from puddles at salinities of 10 per cent sea water, one was from a coral pool at a salinity of 20 per cent, and one from a similar pool at 70 per cent sea water.

Daggy (1945) reared *farauti* from egg to adult at a maximum of 65 per cent sea water and found that "late larval development" was possible in salinities greater than that of sea water. My laboratory investigations showed that fourth instar larvae withstood all concentrations up to 100 per cent sea water for 24 hours, but that the survival was greatly reduced at salinities greater than 30 per cent.

SALINITY

Percentage sea water	*Number of larvae used (4th instar)*	*Percentage alive after 24 hours*
0	21	100
10	7	100
20	11	60
30	21	76
40	22	23
50	23	9
60	15	7
70	20	5
80	18	5
90	15	0
100	36	3

Larval associates have been recorded by Buxton and Hopkins (1927), Belkin *et al.* (1945), and Perry (1946), but no one has recorded the degree of association. *Farauti* occurred mostly (77 per cent) in mixed collections. Percentages of associates were: *C. pullus*, 21; *An. punctulatus*, 16; *C. halifaxi*, 11; *C. squamosus*, 8; *C. annulirostris*, 6; *C. fraudatrix*, 5; *U. argyrotarsis*, 4; others, 6.

Anopheles (Myzomyia) longirostris Brug

Anopheles (*Neomyzomyia*) *longirostris* Brug, 1928, Geneesk. Tijdschr. Nederland. Indië 68: 278. Type locality: Near Upper Digoel River, Dutch New Guinea.

DISTRIBUTION: Dutch New Guinea: Pionierbivak (Lee and Woodhill, 1944); Fakfak, Tanahmerah, hinterland of Geelvink Bay (Swellengrebel and Rodenwaldt, 1932). Northeast New Guinea: Lae (Lee and Woodhill, 1944). Papua: Sinemi, Port Moresby (Lee and Woodhill, 1944); Bulldog (Lee and Woodhill, 1944; Mackerras, 1947); Milne Bay (Lee and Woodhill, 1944; Mackerras, 1947; Author).

HABITAT: Swellengrebel and Rodenwaldt (1932) and Lee and Woodhill (1944) recorded *longirostris* most often from shaded swamps and pools in the jungle or near its fringes. My single collection was taken from a temporary, exposed puddle, in fresh clear water having a sparse amount of algae, in association with *An. farauti*, *An. punctulatus*, and *C. pullus*.

Anopheles (Myzomyia) punctulatus Dönitz

Anopheles punctulatus Dönitz, 1901, Insekten Börse 18: 36. Type locality: Bogadjim, Northeast New Guinea.

Anopheles punctulatus punctulatus Dönitz. Lee and Woodhill (1944: 134); King and Hoogstraal (1946*b*: 153–156); Mackerras (1947: 1–8); Mackerras and Aberdeen (1946: 770).

DISTRIBUTION: Dutch New Guinea: Pionierbivak, Tanahmerah (Lee and Woodhill, 1944; Mackerras, 1947); Aru Islands, Meervlakte, Bataviabivak, Motorbivak, Fakfak, Japen Island, Idore (Lee and Woodhill, 1944); Biak (Lee and Woodhill, 1944; Horsfall and Porter, 1947); Hollandia (Lee and Woodhill, 1944; Rozeboom and Knight, 1946; King and Hoogstraal, 1946*b*); Wamal (Mackerras, 1947); Padaido Islands (Author). Northeast New Guinea: Bogadjim (Dönitz, 1901); Sepik River, Lae, Salamaua, Bulolo, Upper Watut (Lee and Woodhill, 1944); Wau (Lee and Woodhill, 1944; Horsfall and Porter, 1947); Ramu Valley, Maprik (Mackerras, 1947); Wewak (Mackerras and Aberdeen, 1946; Mackerras, 1947); Alexishafen (T. K. Ruebush); Finschhafen, Saidor (Author). Papua: Cape Endaiadere, Koitaki, Dobodura (Lee and Woodhill, 1944); Port Moresby (Lee and Woodhill, 1944; Horsfall and Porter, 1947); Bulldog (Lee and Woodhill, 1944; Mackerras, 1947; Horsfall and Porter, 1947); near mouth of Lakekamu River (Horsfall and Porter, 1947); Milne Bay (Lee and Woodhill, 1944; Mackerras, 1947; Author).

HABITAT:

Total Collections, 151

Habitat	*Number of collections*	*Habitat index*
Puddles	125	83
Ditches	8	5
Swamps	6	4
Creeks: Pot holes	5	3
Creeks: Running	3	2
Ponds	2	1
Borrow pits	1	1
Artificial containers	1	1

*p*H, 27 readings

Range	5.0–7.0
Mode	7.0
Average	6.0

Factor	*Percentage occurrence*
Shaded	16
Exposed	84
Temporary	83
Semi-permanent	10
Permanent	7
Clear	56
Muddy	32
Stagnant	11
Polluted	1
Vegetation	
Absent	55
Present	45
Sparse	37
Moderate	44
Abundant	19
Algae	49
Emergent	11
Overhanging	10
Submerged	22
Floating	8

Punctulatus is widespread throughout New Guinea but collections from the interior are still too meager to prove the interesting hypothesis of Taylor (1934) that *punctulatus* supplants *farauti* in inland localities. This hypothesis is discussed by Lee and Woodhill (1944) and Horsfall and Porter (1947).

Punctulatus was recorded almost entirely (99 per cent) from surface water; the only other habitat utilized was artificial containers. It was collected from a variety of surface habitats but my evidence is overwhelming that only puddles are important. Puddles were the important habitat of both *farauti* and *punctulatus*, but *punctulatus* showed a considerably greater affinity for this habitat (*punctulatus* in puddles, 83 per cent; *farauti* in puddles, 52 per cent). Furthermore, 32 per cent of the *punctulatus* collections were taken from muddy water, in contrast to 17 per cent for *farauti*. Lee and Woodhill (1944), Belkin *et al.* (1945), and Horsfall and Porter (1947) have all emphasized small, temporary surface-water collections as the principal habitat.

In the Solomons, Belkin *et al.* (1945) recorded a contrast in wet- and dry-season habitats. They state that, during the dry season, *punctulatus* almost disappears and is found mainly in streams, whereas, during the wet season, it is found in an endless variety of surface waters. No such contrast was apparent from my observations, nor has such been recorded by others for New Guinea.

Swellengrebel and Rodenwaldt (1932), by listing a great variety of artificial containers, have given undue stress to the utilization of this habitat. Neither Lee and Woodhill (1944) nor Belkin *et al.* (1945) recorded *punctulatus* from artificial containers, and Horsfall and Porter (1947) reported that tin cans were rare habitats.

Lee and Woodhill (1944) and Belkin *et al.* (1945) emphasized that *punctulatus* is found primarily in sunlight. My figure, 84 per cent for exposed situations, is in striking agreement.

Punctulatus was recorded approximately to the same degree both with and without vegetation, and this is in general agreement with Lee and Woodhill (1944) and Belkin *et al.* (1945). However, Horsfall and Porter (1947) state that *punctulatus* habitats are essentially those free of floatage.

Nothing relative to *p*H has been recorded. My data, from 27 readings, give a range of 5 to 7 and a mode of 7, which is significantly higher than the mode of 5 recorded for *farauti*.

Lee and Woodhill (1944) state that *punctulatus* has not been found in brackish water, and none of my 151 collections was from such habitats. However, Horsfall and Porter (1947) did record it rarely from brackish water.

The salt tolerance of *punctulatus* under laboratory conditions apparently has not been reported. My laboratory studies showed that the percentage of fourth instar larvae surviving for 24 hours was greatly reduced only at salinities greater than 50 per cent sea water. Percentage emergence of fourth instar larvae in 10 per cent sea water was identical with that in distilled water, but was significantly reduced at all higher salinities. However, fourth instar larvae emerged to a limited degree at all salinities including 100 per cent sea water. This is particularly interesting because of the absence of brackish water collections.

SALINITY

Percentage sea water	*Number of larvae used (4th instar)*	*Percentage alive after 24 hours*	*Percentage emerging*
0.....	108	97	33
10.....	60	83	33
20.....	58	60	2
30.....	82	74	8
40.....	97	57	6
50.....	87	44	4
60.....	52	19	11
70.....	65	5	2
80.....	64	11	10
90.....	67	4	2
100.....	121	4	3

Nothing has been recorded relative to larval associates. *Punctulatus* was found mostly

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(65 per cent) in mixed collections. Percentages of associates were: *C. pullus*, 18; *An. farauti*, 15; *C. halifaxi*, 12; *C. annulirostris*, 6; *C. squamosus*, 5; others, 9.

Toxorhynchites spp.

In our series of reared individuals, only adult females are represented, so that accurate specific determinations are impossible. However, because many collections of larvae were obtained, it is considered worth while to give my distribution and habitat data for the genus even though possibly more than one species is represented.

DISTRIBUTION: The genus is represented in my records from Padaido Islands, Saidor, Finschhafen, and Milne Bay.

HABITAT:

Total collections, 59

Habitat	*Number of collections*	*Habitat index*
Artificial containers	40	68
Tree holes	9	15
Coconut shells	9	15
Rock holes	1	2

*p*H, 22 readings

Range	4.0–8.0
Mode	5.0–5.5
Average	5.6

Factor	*Percentage occurrence*
Shaded	73
Exposed	27
Temporary	84
Permanent	16
Clear	43
Muddy	10
Stagnant	39
Polluted	8
Vegetation Absent	100

Newkirk (1947) found *Toxorhynchites splendens* commonly in rain barrels and once in a latrine pit at Milne Bay. My specimens were found most abundantly in artificial containers. They occurred to an approximately equal extent in pure (52 per cent) and in mixed collections. Percentages of associates were: *A. scutellaris*, 6; *T. bimaculipes*, 5; *A. albolineatus*, 5; *Arm. breinli*, 5; *C. fragilis*, 5; others, 22.

Tripteroides (Rachisoura) confusa Lee

Tripteroides (*Rachisoura*) *confusa* Lee, 1946, Linn. Soc. N. S. Wales, Proc. 70: 251. Type locality: Milne Bay, Papua.

"Known with certainty only from the type locality but probably quite widely distributed. This is very likely the species which has usually been called *T. atra*, owing to the paratype of that name seen by Edwards not being conspecific with the type." (Lee, 1946.)

Lee (1946) recorded *T. confusa* from tins and coconut shells, in association with *T. bimaculipes*. My single pure collection from Milne Bay was from a taro leaf axil in clear, temporary, shaded water.

Tripteroides (Mimeteomyia) argenteiventris (Theobald)

Polylepidomyia argenteiventris Theobald, 1905, Mus. Nat. Hungarici Ann. 3: 118. Type locality: Paimumu River, Papua.

DISTRIBUTION: Dutch New Guinea: Assike, Merauke, Tanahmerah (Bonne-Wepster, 1938); Hollandia (Lee, 1946). Northeast New Guinea: Tsili Tsili, Nadzab (Lee, 1946); Lae (Lee, 1946; Mackerras, 1946); Finschhafen (Author). Papua: Paimumu River (Theobald, 1905); Dobodura (Lee, 1946); Milne Bay (Lee, 1946; Author).

HABITAT:

Total collections, 7

Habitat	*Number of collections*	*Habitat index*
Coconut shells	4	57
Artificial containers	3	43

*p*H, one reading 4.0

Factor	*Percentage occurrence*
Shaded	100
Temporary	100
Clear	33
Stagnant	56
Polluted	11
Vegetation Absent	100

Brug (1934) reported *argenteiventris* from leaf axils of *Curcuma* plants, and Lee (1946)

stated that it has been found in relatively fresh water in tins, in old coconuts, and in tree holes. I did not collect it from tree holes or from leaf axils. *Argenteiventris* occurred to an approximately equal degree in pure (43 per cent) and in mixed collections. Associates were: *A. scutellaris* (19 per cent), others (38 per cent).

Tripteroides (Tripteroides) bimaculipes (Theobald)

Phoniomyia bimaculipes Theobald, 1905, Mus. Nat. Hungarici Ann. 3: 114. Type locality: Moroka, Papua, and Madang, Northeast New Guinea.

Stegomyia ornata Taylor. Taylor (1914*a*: 189); Breinl (1915: 317); Edwards (1924: 361). Synonymy in Lee (1946: 231).

DISTRIBUTION: Dutch New Guinea: Hollandia (Lee, 1946; King and Hoogstraal, 1946*c*, *f*); Nakasawa, Sapari, Mt. Dafonsero, Doromena (Lee, 1946); Assike, Merauke, Tanahmerah, Explorateurbivak (Bonne-Wepster, 1938); Amsterdam Island (Author). Northeast New Guinea: Madang (Theobald, 1905); Lakekamu Gold Field (Breinl, 1915); Lae (Lee, 1946; Mackerras, 1946); Tsili Tsili (Lee, 1946). Papua: Moroka (Theobald, 1905); Milne Bay (Taylor, 1914*a*; Edwards, 1924; Lee, 1946; Author); Lalapipi, Bulldog, Dobodura, Buna, Cape Endaiadere (Lee, 1946).

HABITAT:

Total collections, 37

Habitat	*Number of collections*	*Habitat index*
Artificial containers	25	68
Coconut shells	5	13
Tree holes	5	13
Leaf axils	2	5

*p*H, 18 readings

Range	4.0–6.5
Mode	5.0
Average	5.4

Factor	*Percentage occurrence*
Shaded	76
Exposed	24
Temporary	100
Clear	51
Stagnant	42
Polluted	7
Vegetation Absent	100

Taylor (1934) found *bimaculipes* in cut ends of bamboo, and Lee (1946) found it in hollow logs, tree holes, artificial containers, and coconut shells. In our surveys it occurred frequently (84 per cent) in mixed collections. Percentages of associated species were: *A. albolineatus*, 19; *A. scutellaris*, 14; *U. nigerrima*, 11; *Toxorhynchites* spp., 7; *A. notoscriptus*, 7; *Arm. milnensis*, 5; *U. argyrotarsis*, 5; others, 16.

Tripteroides (Tripteroides) brevipalpis? Brug

Tripteroides (*Tripteroides*) *brevipalpis* Brug, 1934, Bul. Ent. Res. 25: 508.

Lee (1946) stated that two specimens from Oro Bay and several from Biak (in the University of Queensland collection) differ from *T. brevipalpis* in a few details. He believes that it would be wise to wait for more adequate material before describing this "probably new form." Miss Elizabeth Marks, University of Queensland, in a personal communication to me, states: "The specimens of *T. brevipalpis?* from Biak mentioned by Lee are your series."

DISTRIBUTION: Dutch New Guinea: Padaido Islands, called Biak by Lee in the above discussion (Author). Northeast New Guinea: Finschhafen (W. M. Rogoff). Papua: Oro Bay (Lee, 1946).

HABITAT:

Total collections, 8

Habitat	*Number of collections*	*Habitat index*
Tree holes	4	50
Artificial containers	3	37
Coconut shells	1	12

*p*H, 8 readings

Range	5.0–7.0
Mode	6.0
Average	6.0

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Factor	Percentage occurrence
Shaded	87
Exposed	13
Temporary	100
Clear	50
Stagnant	44
Polluted	6
Vegetation	
Absent	100

In common with all species of *Tripteroides* in our collections, *T. brevipalpis?* was limited entirely to small collections of water in containers. It was found primarily (88 per cent) in mixed collections. Percentages of associates were: *A. scutellaris*, 27; *A. albolineatus*, 27; *C. ?uniformis*, 20; *U. papua*, 14.

Harpagomyia genurostris (Leicester)

Malaya genurostris Leicester, 1908, Cul. Malaya: 258.

DISTRIBUTION: Northeast New Guinea: Saidor (Author); Alexishafen (T. K. Ruebush). Papua: Dobodura, Cape Sudest (King, 1944). Aside from the mimeographed records of King (1944), these are the first New Guinea records of this Oriental species.

HABITAT: Brug (1932) recorded larvae from the leaf axils of *Colocasia* spp., *Crinum* sp., *Susum malayanum aquatica*, and from the inflorescence of *Cyrtandra glabra*. King (1944) reported it from the leaf axil of taro (*Colocasia* sp.).

All of my eight collections were taken from leaf axils (taro, 63 per cent; banana, 37 per cent), in clear, shaded water. This species and *Aedes kochi* were the only larvae with an absolute affinity for any one habitat. *Harpagomyia genurostris* was found associated with *A. kochi* once; otherwise it occurred in pure collections.

Uranotaenia (Uranotaenia) albescens Taylor

Uranotaenia albescens Taylor, 1914, Ent. Soc. London, Trans. 1913 (Part IV): 705.

DISTRIBUTION: Papua: Milne Bay (Lee, 1944*a*; Author).

HABITAT: All New Guinea records are from surface water. Taylor (1914*c*) recorded it from clear, shallow, grassy pools, and Lee (1944*a*) added wheel ruts. My single collection was taken from a clear, sluggish, exposed running creek with abundant emergent vegetation, at a *p*H of 5, and associated with *Anopheles farauti*.

Uranotaenia (Uranotaenia) argyrotarsis Leicester

Uranotaenia argyrotarsis Leicester, 1908, Cul. Malaya: 214.

Uranotaenia argyrotarsis var. King and Hoogstraal (1946*f*: 148).

DISTRIBUTION: Dutch New Guinea: Hollandia (King and Hoogstraal, 1946*f*). Northeast New Guinea: Finschhafen, Saidor (Author). Papua: Milne Bay (Author).

HABITAT:

Total collections, 58

Habitat	Number of collections	Habitat index
Creeks: Pot holes	24	41
Swamps	9	15
Puddles	9	15
Artificial containers	6	10
Creeks: Running	5	9
Borrow pits	4	7
Ditches	1	2

*p*H, 27 readings

Range	4.0–8.0
Mode	5.0
Average	5.5

Factor	Percentage occurrence
Shaded	63
Exposed	37
Temporary	26
Semi-permanent	50
Permanent	24
Clear	65
Muddy	7
Stagnant	26
Polluted	2
Vegetation	
Absent	51
Present	49
Sparse	27
Moderate	46
Abundant	27

Algae	28
Emergent	36
Overhanging	33
Floating	3

Argyrotarsis was quite common in my collections but apparently it has not previously been reported from either Papua or Northeast New Guinea.

It has been recorded by Taylor (1934) and by King and Hoogstraal (1946*f*) from ground pools. Ninety per cent of my collections were from surface water, but 10 per cent were from artificial containers. *Argyrotarsis* occurred mostly (71 per cent) in mixed collections. Percentages of associates were: *C. pullus*, 20; *C. halifaxi*, 13; *An. farauti*, 10; *C. fraudatrix*, 7; *Bironella* spp., 5; others, 16.

Uranotaenia (Pseudoficalbia) nigerrima Taylor

Uranotaenia nigerrima Taylor, 1914, Ent. Soc. London, Trans. 1914 (Part I): 203. Type locality: Milne Bay, Papua; Lakekamu Gold Field, Northeast New Guinea.

DISTRIBUTION: Dutch New Guinea: Pionierbivak (Bonne-Wepster, 1938), Hollandia (King and Hoogstraal, 1946*c*); Padaido Islands (A. G. Humes). Northeast New Guinea: Lakekamu Gold Field (Taylor, 1914*a*); Finschhafen, Saidor (Author). Papua: Milne Bay (Taylor, 1914*a*; Author); Mekeo District (Hill, 1925).

HABITAT:

Total collections, 56

Habitat	*Number of collections*	*Habitat index*
Artificial containers	30	54
Coconut shells	16	28
Spathes and leaves	8	14
Puddles	1	2
Ditch	1	2
*p*H, 9 readings		
Range	4.0–6.5	
Mode	5.5	
Average	5.3	

Factor	*Percentage occurrence*
Shaded	65
Exposed	35
Temporary	98
Semi-permanent	2
Clear	47
Muddy	10
Stagnant	33
Polluted	10
Vegetation	
Absent	100

Nigerrima has been recorded from fallen leaves, fallen coconut bracts, coconut shells, and tree holes (Taylor, 1934; Lee, 1944*a*; King and Hoogstraal, 1946*c*). However, my indices show that spathes and leaves were seldom utilized and that tree holes were never used. Artificial containers and coconut shells were the more important habitats. This species occurred to an approximately equal degree in pure (52 per cent) and mixed collections. Percentages of associates were: *Arm. breinli*, 9; *T. bimaculipes*, 9; *A. albolineatus*, 7; *A. scutellaris*, 6; *Toxorhynchites* spp., 6; *C. fragilis*, 6; others, 5.

Uranotaenia (Pseudoficalbia) papua Brug

Uranotaenia papua Brug, 1924, Bul. Ent. Res. 14: 441. Type locality: Pionierbivak, Dutch New Guinea.

DISTRIBUTION: Dutch New Guinea: Pionierbivak (Brug, 1924); Assike, Merauke, Tanahmerah (Bonne-Wepster, 1938); Padaido Islands (Author). Northeast New Guinea: Finschhafen, Saidor (Author). Papua: Milne Bay (Lee, 1944*a*; Author); Dobodura (King and Hoogstraal, 1946*c*).

HABITAT:

Total collections, 24

Habitat	*Number of collections*	*Habitat index*
Artificial containers	9	38
Spathes and leaves	8	33
Coconut shells	3	13
Rock holes	2	8
Tree holes	1	4
Puddles	1	4
*p*H, 5 readings		
Range	4.0–5.5	
Mode	5.5	
Average	5.1	

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Factor	Percentage occurrence
Shaded	68
Exposed	32
Temporary	100
Clear	73
Stagnant	27
Vegetation Absent	100

U. papua has been reported breeding in rusty tins (Lee, 1944*a*) and in a cup fungus (King and Hoogstraal, 1946*c*). My data show that the only important habitats were artificial containers and spathes and leaves. It occurred chiefly (71 per cent) in pure collections. Percentages of associates were: *A. scutellaris*, 5; *A. albolineatus*, 4; *C. ?uniformis*, 4; *T. brevipalpis?*, 4; others, 12.

Aedes (Mucidus) aurantius chrysogaster (Taylor)

Mucidus chrysogaster Taylor, 1927, Bul. Ent. Res. 18: 67.

DISTRIBUTION: Dutch New Guinea: Padaido Islands (A. G. Humes). Northeast New Guinea: Morobe (Author). Papua: Milne Bay (Author). These are the first records of *chrysogaster* from New Guinea.

HABITAT: *Chrysogaster* was present in five collections from temporary surface water. It occurred twice in puddles, once in a creek pot hole, once in a coral depression, and once in a small artificial hole in active use as a urinal in which the degree of pollution was obviously very high. Taylor (1927) recorded it in a shallow, semi-shaded rock pool containing a large quantity of decaying vegetable matter with *C. halifaxi*. It occurred solely in mixed collections. Associates were: *C. pullus*, *An. punctulatus*, *U. argyrotarsis*, and *C. halifaxi*.

Aedes (Finlaya) candidoscutellum Marks

Aedes (*Finlaya*) *candidoscutellum* Marks, 1947, Queensland Univ., Dept. Biol. Papers 2:1.

DISTRIBUTION: Dutch New Guinea: Hollandia (Marks, 1947*b*). Papua: Milne Bay (Marks, 1947*b*; Author).

HABITAT: Marks (1947*b*) reported this species from tree cavities, and stated that it appeared to show a preference for clear water. My two collections were both from tree holes, in clear, shaded water, associated with *A. keefei*.

Aedes (Finlaya) hollandius King and Hoogstraal

Aedes (*Finlaya*) *hollandius* King and Hoogstraal, 1946, Wash. Ent. Soc. Proc. 48: 38. Type locality: Mount Dafonsero, near Hollandia, Dutch New Guinea.

DISTRIBUTION: Dutch New Guinea: Mount Dafonsero (King and Hoogstraal, 1946*d*); Hollandia (King and Hoogstraal, 1946*c*, *d*). Northeast New Guinea: Finschhafen (King and Hoogstraal, 1946*d*). Papua: Dobodura (King and Hoogstraal, 1946*c*, *d*); Milne Bay (Author).

HABITAT: King and Hoogstraal (1946*c*) record *hollandius* from fallen palm leaves (25 collections), tree holes (2 collections), tin cans (2 collections), and a rock pool (1 collection). I did not find *hollandius* in fallen palm leaves. In four collections it occurred twice in rock holes, once in a tree hole, and once in an artificial container. All of my collections were from temporary, clear, shaded water without vegetation. It occurred mostly (75 per cent) in mixed collections. Associates were: *A. papuensis*, *A. albolineatus*, *A. novalbitarsis*, *C. halifaxi*, and *C. fraudatrix*.

Aedes (Finlaya) keefei King and Hoogstraal

Aedes (*Finlaya*) *keefei* King and Hoogstraal, 1946, Wash. Acad. Sci. Jour. 36: 311. Type locality: K. B. Mission, Milne Bay, Papua.

DISTRIBUTION: Papua: K. B. Mission, Sariba Island (King and Hoogstraal, 1946*a*); Milne Bay (King and Hoogstraal, 1946*a*; Author).

HABITAT:

Total collections, 11

Habitat	*Number of collections*	*Habitat index*
Tree holes	10	91
Coconut shells	1	9
*p*H, 2 readings	4.5,5.0	

Factor	*Percentage occurrence*
Shaded	90
Exposed	10
Temporary	100
Clear	100
Vegetation Absent	100

This uncommon species has been reported only from the Milne Bay area. King and Hoogstraal (1946*a*) recorded it from a stump hole, and in my collections it occurred almost entirely in tree holes. It was found mostly (64 per cent) in mixed collections. Percentages of associates were: *Toxorhynchites* spp., 14; *A. scutellaris*, 14; *A. albolineatus*, 14; *A. candidoscutellum*, 14; *T. bimaculipes*, 8.

Aedes (Finlaya) kochi (Dönitz)

Culex kochi Dönitz, 1901, Insekten Börse 5: 38. Type locality: "Neu-Guinea." Allotype male, Milne Bay, Papua (Marks, 1947*a*).

Aedes poicilia (Theobald) has been recorded from New Guinea by the following: Theobald (1905); Taylor (1914*a*, *b*); Breinl (1915); Bonne-Wepster (1938). However, recent revisions by Knight and Laffoon (1946) and Marks (1947*a*) state that all Australasian records of *poicilia* undoubtedly refer to *kochi*.

DISTRIBUTION: Dutch New Guinea: Fakfak (Bonne-Wepster, 1938); Merauke (Marks, 1947*a*); Amsterdam Island (Author). Northeast New Guinea: Madang, Seleo, Berlinhafen, Mount Hanseman, Astrolabe Bay (Theobald, 1905); Lakekamu Gold Field (Taylor, 1914*a*; Breinl, 1915); Draeger Harbor, Cape Cretin (Edwards, 1926); Bulwa (Taylor, 1934); Finschhafen (Mackerras, 1946); Lae (Mackerras, 1946; Marks, 1947*a*); Saidor (Author). Papua: Samarai Island, Mekeo District (Taylor, 1914*a*); Karema (Taylor, 1914*b*); Wasima Island, Yule Island (Hill, 1925); Milne Bay (Marks, 1947*a*; Author).

HABITAT:

Total collections, 45

Habitat	*Number of collections*	*Habitat index*
Leaf axils	45	100
Banana (37 per cent)		
Pandanus (30 per cent)		
Taro (29 per cent)		
Pineapple (4 per cent)		
*p*H, 16 readings		
Range	4.0–6.0	
Mode	5.5	
Average	5.4	

Factor	*Percentage occurrence*
Shaded	49
Exposed	51
Temporary	100
Clear	85
Stagnant	15
Vegetation Absent	100

A. kochi and *Harpagomyia genurostris* were the only species with an absolute affinity for any one habitat. Both were found solely in leaf axils of various plants. *Kochi* occurred to approximately the same extent in *Pandanus*, taro, and banana, and much more rarely in pineapple plants. This corresponds roughly to the relative abundance of these plants in the areas studied. At Amsterdam Island an index of its incidence in *Pandanus* was determined. All leaf axils containing water in 100 scattered *Pandanus* trees were examined and *kochi* was found in only 2 per cent.

It has been reported to breed in half coconuts (Hill, 1925; Stone and Bohart, 1944) and in leaf axils of *Pandanus*, banana, taro, cunjevoi, *Crinum*, pineapple (Heydon, 1931; Taylor, 1934, 1943; Stone and Bohart, 1944; Marks, 1947*a*). It is significant that *Pandanus* and taro leaf axils are mentioned in almost every habitat reference; banana is omitted in

all except one. Yet my collections from banana axils were the most numerous. Similarly, although coconut shells are mentioned in the literature, Taylor (1943) did not find *kochi* among any of the thousands of mosquitoes taken from coconut shells. And *kochi* was not collected from any of the 174 coconut shells which I examined.

It occurred primarily (86 per cent) in pure collections but was collected with *T. bimaculipes*, *U. papua*, *H. genurostris*, and *A. scutellaris*.

Aedes (Finlaya) notoscriptus (Skuse)

Culex notoscriptus Skuse, 1889, Linn. Soc. N. S. Wales, Proc. (2d series) 3: 1738.

DISTRIBUTION: Dutch New Guinea: Merauke (Brug, 1934; Bonne-Wepster, 1938); Toerai (Bonne-Wepster, 1938); Hollandia (King and Hoogstraal, 1946*a*, *c*, *f*); Amsterdam Island (Author); Padaido Islands (A. G. Humes). Northeast New Guinea: Muina, Seleo, Berlinhafen, Madang, Ragetta Island (Theobald, 1905); Lakekamu Gold Field (Breinl, 1915); Finschhafen, Saidor (Author). Papua: Milne Bay (Taylor, 1914*a*; Author); Dobodura (King and Hoogstraal, 1946*c*).

HABITAT:

Total collections, 47

Habitat	*Number of collections*	*Habitat index*
Tree holes	24	51
Artificial containers	16	34
Coconut shells	6	13
Rock holes	1	2

*p*H, 20 readings	
Range	4.0–6.5
Mode	4.5
Average	5.1

Factor	*Percentage occurrence*
Shaded	72
Exposed	28
Temporary	100
Clear	63
Stagnant	37
Vegetation	
Absent	94
Present, algae	6

The innumerable references to collections of *notoscriptus* in Australia state that tree holes and artificial containers are the most commonly utilized habitats. My collections further bear out the importance of these two habitats.

In New Guinea, King and Hoogstraal (1946*a*, *c*) recorded *notoscriptus* taken from fallen palm leaves, tin cans, and tree holes with *A. plumiferus*, *A. albolineatus*, and *Toxorhynchites splendens*, and Brug (1934) recorded it from tree holes. However, in my collections it was absent from fallen bracts and leaves. It occurred mostly (60 per cent) in pure collections. Percentages of associates were: *A. albolineatus*, 9; *T. bimaculipes*, 5; *Arm. breinli*, 5; *C. fragilis*, 5; others, 16.

Aedes (Finlaya) novalbitarsis King and Hoogstraal

Leucomyia albitarsis Taylor, 1914, Ent. Soc. London, Trans. 1914 (Part I): 194. [Nec *Anisocheleomyia albitarsis* Ludlow, Canad. Ent. 37: 131 = *Aedes* (*Stegomyia*) *desmotes* (Giles), 1904; synonymy by Edwards, 1922, Indian Jour. Med. Res. 10: 464.] Type locality: Lakekamu Gold Field, Northeast New Guinea.

Aedes (*Finlaya*) *novalbitarsis* new name King and Hoogstraal, 1946, Wash. Ent. Soc. Proc. 48: 146.

DISTRIBUTION: Dutch New Guinea: Hollandia (King and Hoogstraal, 1946*c*, *f*); Padaido Islands (Author). Northeast New Guinea: Lakekamu Gold Field (Taylor, 1914*a*); Finschhafen (King and Hoogstraal, 1946*c*). Papua: Dobodura, Oro Bay (King and Hoogstraal, 1946*c*); Milne Bay (Author).

HABITAT:

Total collections, 12

Habitat	*Number of collections*	*Habitat index*
Rock holes	6	50
Puddles	5	42
Tree holes	1	8

*p*H, 5 readings

Range	5.0–6.0
Mode	5.0
Average	5.2

Factor	*Percentage occurrence*
Shaded	50
Exposed	50
Temporary	100
Clear	72
Muddy	14
Stagnant	14
Vegetation	
Absent	75
Present	25
Sparse	67
Abundant	33
Algae	67
Overhanging	33

In 49 collections, King and Hoogstraal (1946*c*) obtained 31 from tree holes, artificial containers, and rock holes, and they listed palm bracts, coconut leaves and husks, and a sea shell as occasional habitats. In contrast, 50 per cent of our collections were from rock holes, 42 per cent from puddles, only 8 per cent from tree holes, and none from artificial containers. King and Hoogstraal (1946*c*) give a very long list of associated species. In our surveys, *novalbitarsis* occurred mostly (67 per cent) in pure collections. Associated species were: *An. punctulatus*, *A. papuensis*, *A. notoscriptus*, *C. halifaxi*, and *A. hollandius*.

Aedes (Finlaya) papuensis (Taylor)

Leucomyia australiensis var. *papuensis* Taylor, 1914, Ent. Soc. London, Trans. 1914 (Part I): 193. Type locality: Milne Bay, Papua.

DISTRIBUTION: Dutch New Guinea: Albatrosbivak (Brug, 1927; Bonne-Wepster, 1938); Doromena (King and Hoogstraal, 1946*c*); Padaido Islands (A. G. Humes). Northeast New Guinea: Lakekamu Gold Field (Breinl, 1915); Finschhafen (King and Hoogstraal, 1946*c*; Author); Gusiko (King and Hoogstraal, 1946*c*); Morobe (Author). Papua: Milne Bay (Taylor, 1914*a*; Author); Higatura (King and Hoogstraal, 1946*c*).

HABITAT:

Total collections, 61

Habitat	*Number of collections*	*Habitat index*
Rock holes	23	38
Puddles	16	26
Artificial containers	9	15
Tree holes	6	10
Coconut shells	5	8
Borrow pits	2	3

*p*H, 9 readings

Range	5.0–6.5
Mode	6.0
Average	5.2

Factor	*Percentage occurrence*
Shaded	46
Exposed	54
Temporary	96
Semi-permanent	4
Clear	62
Muddy	21
Stagnant	17
Vegetation	
Absent	85
Present	15
Moderate	67
Abundant	33
Algae	84
Floating	16

A. papuensis has been recorded from rock pools, tree holes, on paper, drum heads, sunlit ruts, sunlit coral pools (Lee, 1944*a*; King and Hoogstraal, 1946*c*).

A. papuensis and *A. novalbitarsis* were the only *Aedes* with high habitat indices for both surface water and water in containers, and the only *Aedes* with fairly high indices for puddles. *Papuensis* occurred mostly (64 per cent) in mixed collections. Percentages of associates were: *A. albolineatus*, 8; *C. pullus*, 8; *C. halifaxi*, 8; *An. punctulatus*, 6; *Toxorhynchites* spp., 5; others, 29.

Aedes (Finlaya) wallacei Edwards

Aedes wallacei Edwards, 1926, Bul. Ent. Res. 17: 105.

DISTRIBUTION: Dutch New Guinea: Assike, Merauke, Sorong, Tanahmerah (Bonne-Wepster, 1938); Hollandia (King and Hoogstraal,

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1946*c*). Northeast New Guinea: Draeger Harbor, Cape Cretin (Edwards, 1926); Bulwa (Taylor, 1934); Lae (Marks, 1947*a*). Papua: Wasima Island, Yule Island (Hill, 1925); Lalapipi, Dobodura (Marks, 1947*a*); Milne Bay (Marks, 1947*a*; Author).

HABITAT: *Wallacei* has been recorded from leaf axils of banana, taro, pineapple, and *Pandanus*, and from fallen palm leaves (Taylor, 1934; King and Hoogstraal, 1946*c*; Marks, 1947*a*).

My three collections were all from leaf axils—two from pineapple and one from *Pandanus*—in clear, shaded water. *Wallacei* occurred once in a pure collection, once with *U. papua*, and once with *T. bimaculipes*.

Aedes (Skusea) dasyorrhus
King and Hoogstraal

Aedes (*Skusea*) *dasyorrhus* King and Hoogstraal, 1946, Ent. Soc. Wash. Proc. 48 (4): 100. Type locality: Cape Tjeweri, Jatufa Bay, Hollandia, Dutch New Guinea.

DISTRIBUTION: Dutch New Guinea: Hollandia, Biak (King and Hoogstraal, 1946*e*). Papua: Milne Bay (Author).

HABITAT: *Dasyorrhus* has been reported by King and Hoogstraal (1946*e*) from cans at the edge of a mangrove swamp, possibly with partially salt water, and from a metal container.

Our five collections were all from holes in low, horizontally placed tree trunks extending out over the waters of Milne Bay and obviously receiving salt water spray. Three salinity readings showed 30, 50, and 65 per cent of sea water. *A. dasyorrhus* and *C. sitiens* were the only species collected from this very unusual habitat. *Dasyorrhus* occurred primarily in exposed, clear water with sparse amounts of algae, and always in pure collections.

Aedes (Stegomyia) albolineatus
(Theobald)

Scuteomyia albolineata Theobald, 1904, Entomologist 37: 77.

DISTRIBUTION: Dutch New Guinea: Hollandia (Knight and Rozeboom, 1946; King and Hoogstraal, 1946*a*, *c*); Toem (Knight and Rozeboom, 1946); Padaido Islands, Amsterdam Island (Author). Northeast New Guinea: Finschhafen, Saidor (Knight and Rozeboom, 1946; Author); Morobe (Author). Papua: Dobodura (Knight and Rozeboom, 1946); Milne Bay (Knight and Rozeboom, 1946; Author).

HABITAT:

Total collections, 71

Habitat	*Number of collections*	*Habitat index*
Tree holes	37	52
Coconut shells	18	25
Artificial containers	11	16
Leaf axils	2	3
Rock holes	2	3
Swamp	1	1

*p*H, 44 readings

Range	4.5–7.0
Mode	5.0
Average	5.6

Factor	*Percentage occurrence*
Shaded	95
Exposed	5
Temporary	99
Permanent	1
Clear	52
Muddy	4
Stagnant	42
Polluted	2
Vegetation	
Absent	100

Albolineatus and *A. scutellaris* were the only species present in every area studied.

Taylor (1934), Lee (1944*a*), and Knight and Rozeboom (1946) record *albolineatus* from tree holes, coconut shells, artificial containers, leaf axils, fallen leaves, and rock pools. My habitat indices are in agreement with the literature and demonstrate the high affinity of *albolineatus* for tree holes.

Albolineatus occurred almost equally in pure (44 per cent) and in mixed (56 per cent) collections. Percentages of associated species were: *A. scutellaris*, 11; *T. bimaculipes*, 7; *A.*

notoscriptus, 6; *A. papuensis*, 5; *Toxorhynchites* spp., 4; *U. nigerrima*, 4; *C. fragilis*, 4; *T. brevipalpis?*, 4; others, 11.

Aedes (Stegomyia) scutellaris (Walker)

Culex scutellaris Walker, 1859, Linn. Soc. London, Proc. 3: 79. Type locality: Aru Islands.

Culex zonatipes Walker (1861: 229). Synonymy in Stone (1947: 85).

Aedes (*Stegomyia*) *variegatus* Doleschall. Hill (1925: 70); Bonne-Wepster and Brug (1932: 83).

Aedes (*Stegomyia*) *hebrideus* Edwards. Farner and Bohart (1945: 46).

Aedes scutellaris scutellaris King and Hoogstraal (1946*c*: 154); Forbes and Horsfall (1947: 602–603).

Aedes (*Stegomyia*) *scutellaris* Walker. Stone (1947: 85). A topotypic male: Dobo, Aru Islands.

DISTRIBUTION: Dutch New Guinea: Aru Islands (Walker, 1859); Dore (Walker, 1861); Fakfak (Bonne-Wepster, 1938); Doromena (King and Hoogstraal, 1946*c*); Hollandia (King and Hoogstraal, 1946*c*; Toffaleti and King, 1947; Forbes and Horsfall, 1947); Biak (Forbes and Horsfall, 1947); Padaido Islands, Amsterdam Island (Penn, 1947*a*; Author). Northeast New Guinea: Seleo, Berlinhafen, Astrolabe Bay, Bogadjim, Muina (Theobald, 1905); Lakekamu Gold Field (Taylor, 1914*a*; Breinl, 1915); Madang (Hill, 1925); Wau, Salamaua, Bulwa, Bulolo (Taylor, 1934); Saidor (Farner and Bohart, 1945; Penn, 1947*a*; Author); Draeger Harbor (Penn, 1947*a*); Lae (Mackerras, 1946); Finschhafen (Mackerras, 1946; Author); Morobe (Author). Papua: Boirawe, Samarai, Kaile, Yule Island, Wasima (Hill, 1925); Cape Endaiadere (Farner and Bohart, 1945); Milne Bay (Farner and Bohart, 1945; Mackerras, 1946; Penn, 1947*a*; Author); Dobodura (King and Hoogstraal, 1946*c*, *f*); Oro Bay (Forbes and Horsfall, 1947); Moresby (Hill, 1925; Mackerras, 1946).

Taylor (1914*b*) and Breinl (1915) recorded *Stegomyia pseudoscutellaris* Theobald from Samarai Island, Papua. This record probably refers to *A. scutellaris*, since this locality would extend the range of *pseudoscutellaris*—as defined by Farner and Bohart (1945)—several thousand miles westward.

HABITAT: The majority of these data have previously been given by Penn (1947*a*).

Total collections, 251

Habitat	*Number of collections*	*Habitat index*
Artificial containers	114	45
Coconut shells	80	32
Tree holes	27	11
Puddles	15	6
Spathes and leaves	11	4
Leaf axils	3	1
Wells	1	0

*p*H, 172 readings

Range	4.5–8.0
Mode	6.5
Average	6.1

Factor	*Percentage occurrence*
Shaded	66
Exposed	34
Temporary	93
Permanent	7
Clear	45
Muddy	12
Stagnant	41
Polluted	2
Vegetation	
Absent	94
Present, algae	6

Along with *A. albolineatus*, *scutellaris* was present in my collections in every area studied, and ranked second only to *C. pullus* in number of collections.

Brief mention of habitats utilized has been given by Hill (1925), Bonne-Wepster and Brug (1932, 1937, 1939), Taylor (1934), Lee (1944*a*), Farner and Bohart (1945), and King and Hoogstraal (1946*c*). Tree holes, coconut shells, and artificial containers are the habitats most commonly recorded, but fallen leaves, forest pools, and rock holes have also been mentioned.

After its role as a dengue vector was established (Daggy, 1945; Mackerras, 1946) rather

detailed studies of the biology of *A. scutellaris* were published by Mackerras (1946), Forbes and Horsfall (1947), and Penn (1947*a*). All detailed studies have demonstrated that artificial containers are the primary habitat of this important dengue vector.

Scutellaris occurred mostly (73 per cent) in pure collections. The main associate was *A. albolineatus* (6 per cent), but there was an extremely long list of 20 other associates which has been given by Penn (1947*a*).

Aedes (Aedimorphus) vexans (Meigen)

Culex vexans Meigen, 1830, Syst. Bechr. 6: 241.

DISTRIBUTION: Dutch New Guinea: Merauke (Bonne-Wepster, 1938). Northeast New Guinea: Finschhafen, Saidor (Author). Papua: Milne Bay (Lee, 1944*a*; Author).

HABITAT:

Total collections, 12

Habitat	*Number of collections*	*Habitat index*
Puddles	11	92
Borrow pits	1	8
*p*H, one reading	6.5	

Factor	*Percentage occurrence*
Shaded	28
Exposed	72
Temporary	92
Semi-permanent	8
Clear	89
Muddy	11
Vegetation	
Absent	57
Present	43
Moderate	100
Emergent	67
Overhanging	33

Vexans was widely distributed but an uncommon species. The above records are the first for Northeast New Guinea. My limited data and records of Bonne-Wepster and Brug (1937, 1939) and Lee (1944*a*) show that it is exclusively a surface breeder. However, Bonne-Wepster and Brug (1939) found it in fresh, brackish, and salt water, whereas my specimens were entirely from fresh water. It occurred primarily (75 per cent) in mixed collections. Percentages of associates were: *An. punctulatus*, 25; *C. pullus*, 17; others, 33.

Aedes (Aedes) funereus (Theobald)

Skusea funerea Theobald, 1903, Mon. Cul. 3: 292.

DISTRIBUTION: Dutch New Guinea: Wamal, Tanahmerah, Merauke, Assike (Bonne-Wepster, 1938); Hollandia (Toffaleti and King, 1947). Northeast New Guinea: Saidor, Finschhafen (Author). Papua: Mekeo District (Taylor, 1914*a*; Edwards, 1924); Milne Bay (King and Hoogstraal, 1947; Author).

HABITAT:

Total collections, 7

Habitat	*Number of collections*	*Habitat index*
Puddles	3	43
Swamps	2	29
Pond	1	14
Borrow pit	1	14
*p*H, one reading	5.0	

Factor	*Percentage occurrence*
Shaded	71
Exposed	29
Temporary	86
Permanent	14
Clear	86
Muddy	14
Vegetation	
Absent	33
Present	67
Abundant	100
Overhanging	100

These records from Saidor and Finschhafen are the first from Northeast New Guinea. Hill (1922) recorded it in an algae- and grass-covered seepage, in fresh water pools, and in salt puddles in mangrove swamps. Lee (1944*a*) lists it from fresh water swamps. In my collections also, *funereus* occurred in surface water only, and was never found in salt or brackish water. It occurred mostly in

mixed (57 per cent) collections. Percentages of associates were: *An. punctulatus*, 16; *C. pullus*, 10; others, 31.

Aedes (Aedes) lineatus (Taylor)

Skusea funerea Theo. var. *ornata* Theobald, 1905, Mus. Nat. Hungarici Ann. 3: 79. [Nec *Culex ornatus* Meigen, 1818 = *A.* (*Finlaya*) *geniculatus* Oliver, 1791. Synonymy by Edwards, 1921, Bul. Ent. Res. 12: 319.]

Lepidotomyia lineatus Taylor, 1914, Ent. Soc. London, Trans. 1914 (Part I): 191. Type locality: Lakekamu Gold Field, Northeast New Guinea; Mekeo, Papua.

Aedes ornatus Theobald. King and Hoogstraal (1946*c*: 118); Toffaleti and King (1947).

Aedes (*Aedes*) *lineatus* (Taylor). King and Hoogstraal (1947: 118).

DISTRIBUTION: Dutch New Guinea: Toerai, Tanahmerah, Merauke, Assike (Bonne-Wepster, 1938); Hollandia (King and Hoogstraal, 1946*c*; Toffaleti and King, 1947). Northeast New Guinea: Satelberg Mt., Madang (Theobald, 1905); Lakekamu Gold Field (Taylor, 1914*a*); Finschhafen, Saidor (Author). Papua: Mekeo District (Taylor, 1914*a*; Edwards, 1924); Port Moresby (Lee, 1944*a*; Mackerras, 1946); Milne Bay (Author).

HABITAT:

Total collections, 7

Habitat	*Number of collections*	*Habitat index*
Puddles	4	57
Creeks: Pot holes	1	14
Swamps	1	14
Rock hole	1	14
*p*H, one reading	6.5	

Factor	*Percentage occurrence*
Shaded	29
Exposed	71
Temporary	72
Semi-permanent	14
Permanent	14
Clear	86
Muddy	14
Vegetation	
Absent	33
Present	67
Sparse	50
Abundant	50
Algae	67
Emergent	33

All literature records (Hill, 1925; Taylor, 1934; Bonne-Wepster and Brug, 1937; Lee, 1944*a*) are from surface water. Likewise, my collections were entirely from surface water. *Lineatus* occurred mostly (86 per cent) in mixed collections. *An. farauti* was the only common (21 per cent) associate.

Aedes (Aedes) parasimilis King and Hoogstraal

Aedes (*Aedes*) *parasimilis* King and Hoogstraal, 1947, Wash. Acad. Sci. Jour. 37: 125. Type locality: Hollandia, Dutch New Guinea.

Aedes (*Aedes*) *similis* Theobald. Lee (1944*a*: 78). Synonymy in King and Hoogstraal (1947: 125).

DISTRIBUTION: Dutch New Guinea: Hollandia (King and Hoogstraal, 1947); Padaido Islands (A. G. Humes). Northeast New Guinea: Finschhafen (King and Hoogstraal, 1947; Author); Morobe (Author). Papua: Dobodura (King and Hoogstraal, 1947); Milne Bay (Lee, 1944*a*; King and Hoogstraal, 1947; Author).

HABITAT: Lee (1944*a*) reported *parasimilis* from clear pools in marshes, and King and Hoogstraal (1947) reported it from a crayfish hole and from pools at the edge of a swamp. In my five collections it also occurred entirely in surface water, three times from puddles, once from a rock hole, and once from a creek pot hole. The majority of the collections were taken from clear, temporary, shaded water. It occurred mostly (80 per cent) in mixed collections. Percentages of associates were: *C. pullus*, 22; *C. halifaxi*, 14; others, 44.

Aedes (Leptosomatomyia) aurimargo Edwards

Aedes (*?Skusea*) *aurimargo* Edwards, 1922, Bul. Ent. Res. 13: 94.

Leptosomatomyia lateralis Theobald [nec Meigen] (1905: 110).

Aedes (*Leptosomatomyia*) *lateralis* Theobald [nec Meigen]. Edwards (1924).

DISTRIBUTION: Dutch New Guinea: Hollandia (King and Hoogstraal, 1946*c*). Northeast New Guinea: Muina (Theobald, 1905; Edwards, 1924); Finschhafen (Penn, 1947*b*; Author); Lae (Mackerras, 1946).

HABITAT: Of the four collections of *aurimargo*, three were from coconut shells and one from a tree hole. It occurred usually in clear, shaded water and always without vegetation. *Aurimargo* occurred entirely in mixed collections, twice with *Toxorhynchites* spp. and once each with *T. bimaculipes*, *A. scutellaris*, *A. albolineatus*, and *T. argenteiventris*.

Armigeres (Armigeres) breinli (Taylor)

Neosquamomyia breinli Taylor, 1914 (female only), Ent. Soc. London, Trans. 1914 (Part I): 186. Type locality: Milne Bay, Papua.

DISTRIBUTION: Dutch New Guinea: Fakfak (Brug, 1934; Bonne-Wepster, 1938); Hollandia (King and Hoogstraal, 1946*f*); Padaido Islands (Author). Northeast New Guinea: Lae (Lee, 1944*b*; Mackerras, 1946); Finschhafen (Mackerras, 1946; Author); Morobe (Author). Papua: Milne Bay (Taylor, 1914*a*; Lee, 1944*b*; Author); Oro Bay, Dobodura (Lee, 1944*b*).

HABITAT:

Total collections, 32

Habitat	*Number of collections*	*Habitat index*
Coconut shells	30	94
Spathes and leaves	1	3
Artificial containers	1	3

*p*H, 14 readings

Range	4.5–7.5
Mode	4.5
Average	5.2

Factor	*Percentage occurrence*
Shaded	25
Exposed	75
Temporary	100
Clear	9
Muddy	33
Stagnant	16
Polluted	42
Vegetation	
Absent	100

Breinli has been reported from tree holes, coconut shells, and artificial containers, and with *Arm. milnensis* and *C. fragilis* from putrid water in tips of fallen betel nut palms (King and Hoogstraal, 1946*f*). All of the above habitats are represented in my collections. The habitat index of 94 for coconut shells calculated for *breinli* ranks second only to that for *A. kochi* and *H. genurostris*, each of which had an index of 100 for leaf axils. *Breinli* occurred frequently in very highly polluted coconut shells with a strikingly foul smell.

It was collected mostly (86 per cent) in pure collections and in tremendous concentrations of individuals. Associates were: *U. nigerrima*, 4 per cent, and others, 10 per cent.

Arm. breinli and *Arm. milnensis* were undoubtedly the most spectacular species collected, because of their large size and the great concentration of individuals, often in a minute amount of putrid, semi-liquid material.

Armigeres (Armigeres) milnensis Lee

Armigeres milnensis Lee, 1944, Linn. Soc. N. S. Wales, Proc. 69: 215. Type locality: Milne Bay, Papua.

Neosquamomyia breinli Taylor [type male only] (1914*a*: 186).

Armigeres ?breinli Taylor. Hill (1925: 70).

Armigeres obturbans var? Edwards. Lee (1944*a*: 83).

DISTRIBUTION: Dutch New Guinea: Hollandia (King and Hoogstraal, 1946*c*, *f*). Northeast New Guinea: Lakekamu Gold Field (Taylor, 1914*a*; Lee, 1944*b*); Lae (Lee, 1944*b*; Mackerras, 1946); Finschhafen (Mackerras, 1946); Morobe (Author). Papua: Mekeo District (Hill, 1925; Lee, 1944*b*); Bulldog, Lalapipi (Lee, 1944*b*); Milne Bay (Edwards, 1924; Lee, 1944*b*; Author).

HABITAT:

Total collections, 38

Habitat	*Number of collections*	*Habitat index*
Coconut shells	19	50
Artificial containers	9	24
Tree holes	7	18
Borrow pits (one was a urinal pit)	3	8

*p*H, 11 readings

Range	4.0–7.0
Mode	6.5
Average	5.8

Factor	*Percentage occurrence*
Shaded	43
Exposed	57
Temporary	92
Semi-permanent	8
Clear	20
Muddy	11
Stagnant	32
Polluted	37
Vegetation	
Absent	100

Hill (1925) records *milnensis* from tree holes, Lee (1944*a*) from coconut shells, and King and Hoogstraal (1946*c*) report it associated with *Arm. breinli* and *C. fragilis* in putrid water in tips of fallen betel nut palms. My collections demonstrate the importance of coconut shells. However, *milnensis* utilized this habitat to a lesser degree (50) than did *breinli* (94).

As with *breinli*, the present species often occurred in polluted water and in great concentrations of individuals. In one collection the larvae were found in dense masses in a small pit filled with urine. Feng (1938*b*) states that in China the usual habitat of *Arm. obturbans* is tubs of fermenting urine. *Milnensis* occurred mostly (84 per cent) in pure collections. Percentages of associates were: *Arm. breinli*, 3; *T. bimaculipes*, 3; *A. scutellaris*, 3; others, 7.

Culex (Lutzia) halifaxi Theobald

Culex halifaxi Theobald, 1903, Mon. Cul. 3: 231.

DISTRIBUTION: Dutch New Guinea: Albatrosbivak (Brug, 1927; Bonne-Wepster, 1938); Manokwari (Brug and Haga, 1923); Toerai (Brug and Haga, 1923; Bonne-Wepster, 1938); Assike, Fakfak, Merauke, Tanahmerah (Bonne-Wepster, 1938); Hollandia (King and Hoogstraal, 1946*b*, *f*); Padaido Islands (Author). Northeast New Guinea: Finschhafen, Saidor, Morobe (Author). Papua: Mekeo District (Hill, 1925); Milne Bay (Author).

HABITAT:

Total collections, 183

Habitat	*Number of collections*	*Habitat index*
Puddles	118	65
Artificial containers	26	14
Creeks: Pot holes	22	12
Ditches	5	3
Borrow pits	5	3
Rock holes	2	1
Pond	1	–
Swamp	1	–
Well	1	–
Coconut shell	1	–
Tree holes	1	–

*p*H, 31 readings

Range	4.0–8.0
Mode	6.5
Average	6.0

Factor	*Percentage occurrence*
Shaded	32
Exposed	68
Temporary	81
Semi-permanent	17
Permanent	2
Clear	41
Muddy	28
Stagnant	25
Polluted	6
Vegetation	
Absent	68
Present	32
Sparse	33
Moderate	45
Abundant	22
Algae	59
Emergent	24
Overhanging	11
Floating	4
Submerged	2

Halifaxi was common in every locality studied and ranked third in total number of

collections. These are apparently the first records from Northeast New Guinea.

Hill (1925), Bonne-Wepster and Brug (1937), and Lee (1944*a*) list a great variety of habitats: wells, marshes, jungle pools, roadside ditches, tree holes, swamps, rock pools, wheel ruts, slit trenches, and artificial containers. However, Bonne-Wepster and Brug (1939) record *halifaxi* mostly from "earthbound" breeding places, and King and Hoogstraal (1946*b*, *f*) mention only pools. In my collections it was found also in a great variety of habitats, but the figure (65 per cent) for puddles far surpasses that of any other habitat.

It occurred mostly (82 per cent) in mixed collections. Percentages of associates were: *C. pullus*, 25; *An. punctulatus*, 14; *An. farauti*, 11; *U. argyrotarsis*, 6; *C. annulirostris*, 6; *C. papuensis*, 5; others, 15.

Culex (Neoculex) brevipalpis (Giles)

Stegomyia brevipalpis Giles, 1902, Handbook Gnats, 2d ed., p. 384.

DISTRIBUTION: Dutch New Guinea: Hollandia (King and Hoogstraal, 1946*c*, *f*). Papua: Milne Bay (Author).

HABITAT: *Brevipalpis* is a rare species and the above record is the first from Papua. Both of my collections were from tree holes. One was from clear, exposed water; the other from clear, stagnant, shaded water. It was found with *Aedes papuensis* and *Aedes scutellaris*. Brug (1932) and King and Hoogstraal (1946*c*) have also recorded *brevipalpis* from tree holes.

Culex (Lophoceratomyia) fraudatrix (Theobald)

Lophoceratomyia fraudatrix Theobald, 1905, Mus. Nat. Hungarici Ann. 3: 94. Type locality: Madang and Bogadjim, Northeast New Guinea.

DISTRIBUTION: Dutch New Guinea: Assike, Tanahmerah (Bonne-Wepster, 1938); Hollandia (T. K. Ruebush). Northeast New Guinea: Madang, Bogadjim (Theobald, 1905); Finschhafen, Saidor (Author). Papua: Milne Bay (Author).

HABITAT:

Total collections, 37

Habitat	*Number of collections*	*Habitat index*
Swamps	9	24
Creeks: Pot holes	9	24
Puddles	6	16
Ponds	4	11
Creeks: Running	3	8
Artificial containers	3	8
Rock holes	1	3
Ditch	1	3
Spathes and leaves	1	3

*p*H, 14 readings

Range	4.5–8.0
Mode	5.0
Average	5.6

Factor	*Percentage occurrence*
Shaded	76
Exposed	24
Temporary	30
Semi-permanent	27
Permanent	43
Clear	73
Muddy	1
Stagnant	26
Vegetation	
Absent	44
Present	56
Sparse	15
Moderate	55
Abundant	30
Algae	21
Emergent	28
Overhanging	37
Submerged	7
Floating	7

It is rather surprising that this common species has not been previously recorded from Papua.

Lee (1944*a*) reported *fraudatrix* from shallow wells. Knight *et al.* (1944) list it from leafy pools, footprints, and brackish mangrove or fresh water pot holes. My collections also were mostly from surface water but they were not collected in brackish situations.

Culex fraudatrix was one of the few species found to a high degree in permanent water

collections, and one of the very few occurring in a significant measure in extensive swampy areas. It was found mostly (84 per cent) in mixed collections. Percentages of associates were: *An. farauti*, 26; *U. argyrotarsis*, 17; *An. punctulatus*, 7; *Bironella* spp., 7; *C. annulirostris*, 6; *An. bancrofti pseudobarbirostris*, 6; *C. halifaxi*, 4; others, 11.

Culex (Lophoceratomyia) uniformis Theobald

Culex uniformis Theobald, 1905, Bombay Nat. Hist. Soc. Jour. 16: 245.

A limited number of specimens closely resembling *C. uniformis* were collected from Woendi Island. Since no recent comprehensive comparative study of the subgenus *Lophoceratomyia* has been undertaken and since, apparently, all definite records of *uniformis* are limited to the Indian Region, it seems best to note that my material was similar in a general way to *uniformis*. My specimens, which have been placed in the U. S. National Museum, may properly represent an undescribed species.

DISTRIBUTION: Dutch New Guinea: Hollandia (King and Hoogstraal, 1946*c*); Padaido Islands (Author).

HABITAT: The four collections of this species were from temporary water: two from artificial containers, one from a tree hole, and one from a puddle. It was found to the same extent in shaded and exposed, clear and stagnant water. Algae were present in one collection. *Uniformis?* was always in mixed collections with *A. scutellaris*, *T. brevipalpis?*, *U. papua*, *A. albolineatus*, and *C. pullus*.

Culex (Culiciomyia) fragilis Ludlow

Culex fragilis Ludlow, 1903, N. Y. Ent. Soc. Jour. 11: 142.

Culex (*Culiciomyia*) *papuensis* of Lee [nec Taylor] (1944*a*: 96). Synonymy in King and Hoogstraal (1946*f*: 148).

DISTRIBUTION: Dutch New Guinea: Hollandia (King and Hoogstraal, 1946*f*); Padaido Islands (Author). Northeast New Guinea: Finschhafen, Saidor (Author). Papua: Milne Bay (Lee, 1944*a*; Author).

HABITAT:

Total collections, 80

Habitat	*Number of collections*	*Habitat index*
Artificial containers	50	63
Coconut shells	9	11
Puddles	8	10
Creek: Pot holes	4	5
Tree holes	3	4
Ponds	2	2
Spathes and leaves	1	1
Rock holes	1	1
Ditch	1	1
Creek: Running	1	1

*p*H, 40 readings

Range	5.0–7.0
Mode	6.0
Average	5.8

Factor	*Percentage occurrence*
Shaded	62
Exposed	38
Temporary	90
Semi-permanent	6
Permanent	4
Clear	12
Muddy	24
Stagnant	21
Polluted	43
Vegetation	
Absent	92
Present	8
Sparse	84
Moderate	16
Algae	63
Emergent	12
Submerged	25

The records given here are apparently the first for Northeast New Guinea.

King and Hoogstraal (1946*f*) stated that, of 62 larval collections, about half were taken from temporary and semi-permanent ground pools, especially with stagnant, more or less foul or algae-filled water, in all degrees of shade, whereas the others were obtained from tree holes and artificial containers, usually with rotting vegetation and in shade. Three collections were made from putrid water in the tips of fallen betel nut palms. Lee (1944*a*)

recorded it from coconut shells, polluted water in tins, refuse pits, and butts of sago palms. My data show a greater use of artificial containers than is indicated in the records of King and Hoogstraal. Both surface water and water in containers were utilized but the index of 63 for artificial containers far surpasses that of any other habitat. More than half of the collections were in shade, as mentioned by King and Hoogstraal; furthermore, the figure for polluted water (43 per cent) was higher than for any other species.

Fragilis occurred mostly in mixed (63 per cent) collections. Percentages of associates were: *C. pullus*, 12; *C. halifaxi*, 10; *A. scutellaris*, 10; *A. albolineatus*, 7; *A. notoscriptus*, 5; *Toxorhynchites* spp., 4; *U. nigerrima*, 4; others, 11. This list of associates is essentially similar to that given by King and Hoogstraal (1946*f*).

Culex (Culiciomyia) papuensis (Taylor)

Melanconion papuensis Taylor, 1914, Ent. Soc. London, Trans. 1914 (Part I): 201. Type locality: Lakekamu Gold Field, Northeast New Guinea.

Culex (*Culiciomyia*) *pallidothorax* of Lee [nec Theobald] (1944*a*: 95). Synonymy in King and Hoogstraal (1946*f*: 147).

DISTRIBUTION: Dutch New Guinea: Assike, Merauke, Tanahmerah (Bonne-Wepster, 1938); Hollandia (King and Hoogstraal, 1946*f*). Northeast New Guinea: Lakekamu Gold Field (Taylor, 1914*a*); Finschhafen (Author). Papua: Dobodura (King and Hoogstraal, 1946*f*); Milne Bay (Author).

HABITAT:

Total collections, 46

Habitat	*Number of collections*	*Habitat index*
Artificial containers	18	39
Puddles	11	24
Creeks: Pot holes	8	17
Borrow pits	4	9
Ditches	3	6
Rock hole	1	2
Tree hole	1	2

*p*H, 5 readings

Range	5.0–7.0
Mode	5.5
Average	5.9

Factor	*Percentage occurrence*
Shaded	56
Exposed	44
Temporary	67
Semi-permanent	33
Clear	45
Muddy	11
Stagnant	16
Polluted	22
Vegetation	
Absent	92
Present	8
Sparse	33
Moderate	33
Abundant	33
Algae	33
Emergent	33
Overhanging	33

Lee (1944*a*) and King and Hoogstraal (1946*f*) have recorded *papuensis* from a long list of habitats which may be grouped into artificial containers of many types, tree holes, surface pools, and wells. In my collections it was one of the few species which occurred quite frequently in both surface water and in water in containers. It must be noted that the collections from creek pot holes were nearly all in polluted water from a near-by shower drain.

Papuensis was found mostly (74 per cent) in mixed collections. Percentages of associated species were: *C. pullus*, 27; *C. halifaxi*, 21; *An. punctulatus*, 5; *An. farauti*, 5; *U. argyrotarsis*, 5; others, 11. Associates given by King and Hoogstraal (1946*f*) agree only roughly with the above.

Culex (Culiciomyia) pullus Theobald

Culex pullus Theobald, 1905, Mus. Nat. Hungarici Ann. 3: 87. Type locality: Muina, Northeast New Guinea.

Culex muticus Edwards. Edwards (1924: 6). Synonymy in Edwards (1926: 121); Hill (1925: 74); Brug (1927: 358); Brug (1934: 517); Bonne-Wepster (1938: 206–212).

Culex (*Culiciomyia*) *pallidothorax* of Bonne-Wepster [nec Theobald] (1938: 206–212). Questionable synonym in King and Hoogstraal (1946*f*: 143, 149).

DISTRIBUTION: Dutch New Guinea: Merauke (Edwards, 1924; Edwards, 1926; Bonne-Wepster, 1938); Mamberano River (Edwards, 1926); Pionierbivak (Edwards, 1926; Bonne-Wepster, 1938); Albatrosbivak (Brug, 1927; Brug, 1934; Bonne-Wepster, 1938); Fakfak (Brug, 1934; Bonne-Wepster, 1938); Manokwari, Tanahmerah, Assike, Toerai (Bonne-Wepster, 1938); Hollandia (King and Hoogstraal, 1946*c*, *f*); Padaido Islands (Author). Northeast New Guinea: Muina (Theobald, 1905); Finschhafen (King and Hoogstraal, 1946*c*; Author); Saidor, Morobe (Author). Papua: Milne Bay (Lee, 1944*a*; Author).

HABITAT:

Total collections, 289

Habitat	*Number of collections*	*Habitat index*
Puddles	178	62
Artificial containers	38	13
Creeks: Pot holes	33	11
Borrow pits	12	4
Ditches	12	4
Swamps	5	2
Creeks: Running	3	1
Coconut shells	3	1
Tree holes	2	1
Marsh	1	–
Rock holes	1	–
Spathes and leaves	1	–

*p*H, 52 readings

Range	4.0–7.0
Mode	5.5
Average	5.7

Factor	*Percentage occurrence*
Shaded	33
Exposed	67
Temporary	77
Semi-permanent	20
Permanent	3
Clear	49
Muddy	20
Stagnant	24
Polluted	7
Vegetation	
Absent	61
Present	39
Sparse	29
Moderate	47
Abundant	24
Algae	46
Emergent	23
Overhanging	18
Submerged	7
Floating	6

Pullus ranked first in number of collections. It was found in every locality studied except Amsterdam Island.

It has previously been recorded from a great variety of habitats. Brug (1934) lists a beached canoe, a tree hole, a jungle pool. Lee (1944*a*) gives fresh-water wheel ruts, grassy drains, coconut shells, tarpaulins. King and Hoogstraal (1946*f*) state that, in 150 collections, 16 were from tree holes and artificial containers, the others from shaded and sunlit ground water of all types except from permanent ponds and brackish water. My collections were also from a wide range of habitats, but the index of 62 for puddles far outweighs any other habitat. *Pullus* was found most often in clear water exposed to full sunlight, where vegetation was entirely absent.

It must be emphasized that the puddles so widely used by *pullus* were, almost entirely, recently formed ruts of vehicles or footprints. Such habitats were most numerous in the low coastal strips, on the sites of abandoned coconut plantations which were the principal centers of military activity in these areas. These habitats are the source of man-made malaria now so widely discussed in the literature in connection with habitat observations on *Anopheles punctulatus* and *Anopheles farauti*. However, little mention has been made thus far of the very general occurrence of both *Culex pullus* and *Culex halifaxi* with the anophelines in such situations.

Pullus occurred mostly (76 per cent) in mixed collections. Percentages of associates were: *C. halifaxi*, 17; *An. farauti*, 15; *An. punctulatus*, 13; *U. argyrotarsis*, 6; *C. annulirostris*, 4; *C. papuensis*, 4; *C. squamosus*, 4; others, 13. King and Hoogstraal (1946*f*) give a briefer list of associates.

Culex (Acallyntrum) bicki Stone and Penn

Culex bicki Stone and Penn, 1947, Wash. Acad. Sci. Jour. 37: 89. Type locality: Toem, Dutch New Guinea.

Culex (*Acallyntrum*) *bicki* Stone and Penn (1948: 109).

DISTRIBUTION: Dutch New Guinea: Toem (Stone and Penn, 1947). Papua: Milne Bay (Stone and Penn, 1947; Author).

HABITAT: My single collection of *bicki* was a pure collection from a clear, shaded *Pandanus* leaf axil with abundant debris. Stone and Penn (1947) recorded it from sago and taro leaf axils.

Culex (Culex) annulirostris Skuse

Culex annulirostris Skuse, 1889, Linn. Soc. N. S. Wales, Proc. (2d series) 3: 1737.

DISTRIBUTION: Dutch New Guinea: Albatrosbivak (Brug, 1927; Bonne-Wepster, 1938); Assike, Merauke, Tanahmerah (Bonne-Wepster, 1938); Padaido Islands, Amsterdam Island (Author). Northeast New Guinea: Lakekamu Gold Field (Taylor, 1914*a*); Saidor (Author). Papua: Milne Bay (Author).

HABITAT:

Total collections, 64

Habitat	*Number of collections*	*Habitat index*
Puddles	48	75
Creek: Pot holes	4	6
Ditches	4	6
Borrow pits	3	5
Artificial containers	3	5
Ponds	1	2
Wells	1	2

*p*H, 18 readings	
Range	5.0–7.0
Mode	5.0, 7.0
Average	6.0

Factor	*Percentage occurrence*
Shaded	96
Exposed	4
Temporary	80
Semi-permanent	17
Permanent	3
Clear	50
Muddy	21
Stagnant	26
Polluted	3
Vegetation	
Absent	57
Present	43
Sparse	25
Moderate	45
Abundant	30
Algae	74
Emergent	16
Submerged	5
Floating	5

Specific locality records for New Guinea are few, the typical reference being "along all coasts of the Australasian Region." No doubt most authors have considered it too common to merit specific records. My collections from Milne Bay are apparently the first records from Papua.

Bonne-Wepster and Brug (1937), Taylor (1943), and Lee (1944*a*) report *annulirostris* mostly from fresh surface water but also from brackish habitats. In my collections it was found almost entirely in surface water (primarily puddles, 75 per cent) but never in brackish situations. The puddles commonly utilized were usually old, large, rather deep, and well vegetated in contrast with the small, shallow, muddy, and non-vegetated puddles so often utilized by *C. pullus*, *C. halifaxi*, and *An. punctulatus*. Furthermore, in contrast with the above species, *annulirostris* was found almost entirely (96 per cent) in shade, the highest per cent recorded for any surface water species.

Annulirostris occurred mostly (74 per cent) in mixed collections. Percentages of associates were: *C. pullus*, 16; *An. punctulatus*, 16; *An. farauti*, 16; *C. halifaxi*, 13; others, 13.

Culex (Culex) fatigans Wiedemann

Culex fatigans Wiedemann, 1823, Aussereur. Zweifl. Insec. 1: 10.

Taeniorhynchus acer Walker. Theobald (1905: 106).

DISTRIBUTION: Dutch New Guinea: Fak-

fak, Manokwari (Brug and Haga, 1923; Bonne-Wepster, 1938); Assike, Merauke, Tanahmerah (Bonne-Wepster, 1938); Hollandia (Toffaleti and King, 1947); Padaido Islands (Author). Northeast New Guinea: Madang (Theobald, 1905; Hill, 1925); Bogadjim, Mount Hansemann, Yomo (Theobald, 1905); Lakekamu Gold Field (Breinl, 1915). Papua: Port Moresby (Taylor, 1914*a*; Hill, 1925); Yule Island, Samarai (Hill, 1925).

HABITAT: Bonne-Wepster and Brug (1937, 1939), Taylor (1943), and Lee (1944*a*) record *fatigans* from a variety of domestic habitats, and emphasize its occurrence in polluted water. I have a single, pure collection from the Padaido Islands, taken from a shaded well in stagnant water without vegetation.

Culex (Culex) sitiens Wiedemann

Culex sitiens Wiedemann, 1828, Aussereur. Zweifl. Insec. 1: 543.

Culicelsa annulirostris Skuse var. *milni* Taylor (1914*a*: 196).

Culex sitiens var. *milni* Taylor. Breinl (1915: 317).

Culex sitiens Edw. Brug and Haga (1923: 640).

Culex (*Culex*) *?sitiens* Wied. Brug (1934: 514).

DISTRIBUTION: Dutch New Guinea: Albatrosbivak (Brug, 1927; Bonne-Wepster, 1938); Pionierbivak (Brug and Haga, 1923; Bonne-Wepster, 1938); Sorong (Brug, 1934; Bonne-Wepster, 1938); Fakfak, Merauke, Tanahmerah, Toerai, Wamal (Bonne-Wepster, 1938); Hollandia (Toffaleti and King, 1947); Padaido Islands, Amsterdam Island (Author). Northeast New Guinea: Madang (Hill, 1925); Lakekamu Gold Field (Breinl, 1915); Finschhafen (Author). Papua: Milne Bay (Taylor, 1914*a*; Author); Yule Island, Samarai, Mekeo District, Moresby District (Hill, 1925).

HABITAT:

Total collections, 123

Habitat	*Number of collections*	*Habitat index*
Coral pools	115	93
Brackish puddles	4	3
Fallen trees on beach	2	2
Ditch	1	1
Artificial container	1	1

*p*H, 117 readings

Mode	7.0
Average	7.0

Factor	*Percentage occurrence*
Exposed	100
Temporary	5
Semi-permanent	95
Clear	88
Muddy	2
Murky	10
Vegetation	
Absent	36
Present	64
Algae	99
Emergent	1
Salinity	
Percentage sea water	
0– 18	66
18– 37	7
37– 55	6
55– 74	5
74– 93	9
93–100	6

Sitiens is apparently widely distributed along the north coast of New Guinea. However, it was common only at Amsterdam Island where 117 collections were obtained. The literature (Hill, 1925; Bonne-Wepster and Brug, 1937, 1939; Taylor, 1943; Lee, 1944*a*) gives a much wider variety of habitats than we have observed, often assigning equal importance to fresh and brackish water. In my collections the association with brackish water was absolute. But, for the most part, it was found in salinities ranging from 0 to 18 per cent sea water. It was found only along the beach in situations fully exposed to sunlight and subjected to salt spray or to storm tides. It occurred almost entirely (98 per cent) in pure collections. Its only associate was *An. farauti*.

Culex (Culex) squamosus (Taylor)

Culicada squamosa Taylor, 1914, Ent. Soc. London, Trans. 1913 (Part IV): 691.

Trichopronomyia annulata Theobald (1905: 98).

DISTRIBUTION: Dutch New Guinea: Upper Digoel River (Brug, 1934); Merauke (Bonne-Wepster, 1938); Padaido Islands (Author). Northeast New Guinea: Madang (Theobald, 1905; Edwards, 1924); Finschhafen (Author). Papua: Milne Bay (Lee, 1944*a*; Author).

HABITAT:

Total collections, 49

Habitat	*Number of collections*	*Habitat index*
Puddles	22	45
Creeks: Running	17	35
Creeks: Pot holes	7	14
Ditches	2	4
Ponds	1	2

*p*H, 9 readings

Range	5.0–7.0
Mode	5.0, 5.5
Average	5.7

Factor	*Percentage occurrence*
Shaded	11
Exposed	89
Temporary	45
Semi-permanent	18
Permanent	37
Clear	76
Muddy	9
Stagnant	15
Vegetation	
Absent	15
Present	85
Sparse	27
Moderate	35
Abundant	38
Algae	61
Emergent	11
Overhanging	2
Submerged	11
Floating	15

Squamosus was recorded from surface water only. It had a high affinity for the more permanent puddles and for creeks. The most striking habitat factor was vegetation, which was present in 85 per cent of the collections and was typically dense masses of algae flourishing in full sunlight. Hill (1925), Brug (1934), and Lee (1944*a*) also list surface water habitats but they apparently did not observe any striking abundance and frequency of vegetation in association with *squamosus*.

Squamosus occurred to approximately the same degree in pure (43 per cent) and in mixed (57 per cent) collections. Percentages of associates were: *An. farauti*, 18; *C. pullus*, 16; *An. punctulatus*, 12; *C. halifaxi*, 6; others, 5.

SUMMARY

Distribution

Edwards (1924) included 145 species from the Australasian Region and recorded 47 from New Guinea. Bonne-Wepster (1938) listed 121 non-anopheline species from the island. In 1944 Knight *et al.* listed 238 species from the Australasian Region and recorded 124 from New Guinea. I have specific locality records for 47 species. I believe that this discrepancy is due primarily to the fact that I engaged in routine surveys of each area rather than in intensive searching for species in unusual and inaccessible habitats.

In this paper many species are reported for the first time from major subdivisions of New Guinea. First records from Papua are presented for *U. argyrotarsis*, *A. candidoscutellum*, *A. dasyorrhus*, *C. brevipalpis*, *C. fraudatrix*, and *C. annulirostris*. First Northeast New Guinea records are presented for *U. argyrotarsis*, *U. papua*, *A. vexans*, *C. halifaxi*, *C. fragilis*, and *H. genurostris*. The collections of *A. aurantius chrysogaster* from Morobe and Milne Bay are apparently the first New Guinea records of the subspecies.

In assembling the records it became clear that frequently, in past surveys, novelties were recorded to the almost complete neglect of certain common species. Thus *Culex pullus*, one of the species most frequently encountered in my collections and present in every area studied, is represented in the literature by only two records from Northeast New Guinea and by a single one from Papua.

Table 1 summarizes distribution records from the study areas. The following generalizations may be given.

TABLE 1
SPECIES RECORDED FROM THE DETAIL STUDY AREAS

SPECIES	MILNE BAY	MOROBE	FINSCH-HAFEN	SAIDOR	PADAIDO	AMSTER-DAM
B. soesiloi	x					
B. travestitus	x					
An. b. pseudobarbirostris				x		
An. farauti	x		x	x	x	x
An. longirostris	x					
An. punctulatus	x		x	x	x	
Toxorhynchites spp.	x		x	x	x	
T. confusa	x					
T. argenteiventris	x		x			
T. bimaculipes	x					x
T. brevipalpis?			x		x	
H. genurostris				x		
U. albescens	x					
U. argyrotarsis	x		x	x		
U. nigerrima	x		x	x	x	
U. papua	x		x	x	x	
A. a. chrysogaster	x	x			x	
A. candidoscutellum	x					
A. hollandius	x					
A. keefei	x					
A. kochi	x			x		x
A. notoscriptus	x		x	x	x	x
A. novalbitarsis	x				x	
A. papuensis	x	x	x		x	
A. wallacei	x					
A. dasyorrhus	x					
A. albolineatus	x	x	x	x	x	x
A. scutellaris	x	x	x	x	x	x
A. vexans	x		x	x		
A. funereus	x		x	x		
A. lineatus	x		x	x		
A. parasimilis	x	x	x		x	
A. aurimargo			x			
Arm. breinli	x	x	x		x	
Arm. milnensis	x	x				
C. halifaxi	x	x	x	x	x	
C. brevipalpis	x					
C. fraudatrix	x		x	x		
C. ?uniformis					x	
C. fragilis	x		x	x	x	
C. papuensis	x		x			
C. pullus	x	x	x	x	x	
C. bicki	x					
C. annulirostris	x			x	x	x
C. fatigans					x	
C. sitiens	x		x		x	x
C. squamosus	x		x		x	

1. Nearly all of the 47 species recorded were found at Milne Bay. A significant number of species found at Milne Bay dropped from the list only at Amsterdam Island. The apparent spotty distribution of certain species is thought to be due largely to habitat availability at the particular locality rather than to distinct range limitations.

2. A distance of approximately 1,300 miles separates Milne Bay from Padaido and Amsterdam Islands, yet the latter localities added only *C. fatigans*, *C. ?uniformis*, and *T. brevi-*

palpis? to the list for Milne Bay.

3. Four species of Anopheles (*farauti*, *punctulatus*, *bancrofti pseudobarbirostris*, *longirostris*) are recorded. *Bancrofti* and *longirostris* were rare; the former was found only at Saidor and the latter only at Milne Bay. *Farauti* and *punctulatus* were common to extremely abundant in nearly every area. Because of their abundance and widespread distribution it seems that only these could be significant malaria vectors in New Guinea.

4. *Aedes scutellaris* was the only species common in every locality. Because of its abundance and widespread distribution, and considering the results of transmission experiments, this species is of considerably greater significance as a dengue vector than all other culicines.

5. *Aedes albopictus*, so frequently reported as common, was not recorded. *Culex fatigans* was found only in a single collection from the Padaido Islands. *Aedes aegypti* was represented by a single adult collection from Samarai Island.

6. Based on distribution and numerical abundance, *C. pullus*, *C. halifaxi*, *A. albolineatus*, and *A. notoscriptus* are potentially important pest species along the north coast. However, practically nothing on their biting habits has been recorded. In particular areas other species may assume local importance, as *Armigeres milnensis*, which was exceptionally abundant at Milne Bay, and *Culex sitiens* at Amsterdam Island.

Habitats

Table 2 lists the number of collections from

TABLE 2
COLLECTION SUMMARY ACCORDING TO HABITAT AND LOCALITY

	MILNE BAY	MOROBE	FINSCH-HAFEN	SAIDOR	PADAIDO ISLAND	AMSTER-DAM ISLAND	TOTAL	PER CENT
Fresh Surface Water								
Natural								
Creeks: Running.....(P)*	57		1	1			59	3.9
Creeks: Pot holes.....(S)	91		2				93	6.1
Swamps.....(P)	23	2		12			37	2.5
Ponds.....(P)	5			5			10	0.7
Marshes.....(P)	4					12	16	1.1
Artificial								
Puddles.....(T)	320	1	4	28	14	7	374	24.8
Borrow pits.....(S)	18		1	2			21	1.3
Ditches.....(S)	29			1			30	2.0
Wells.....(P)				1	2		3	0.2
Fresh Water in Containers								
Natural								
Shells.....(T)					1		1	0.1
Rock holes.....(T)	34						34	2.2
Leaf axils.....(T)	50			9		5	64	4.2
Spathes and leaves....(T)	9		2	1	5	5	22	1.4
Tree holes.....(T)	76		3	8	20	12	119	7.9
Coconut shells.....(T)	75		4	8	39	48	174	11.6
Artificial.....(T)	241		17	20	43	4	325	21.6
Brackish Water								
Coral pools.....(S)						117	117	7.8
Puddles.....(T)	2						2	0.1
Tree holes.....(T)	5					2	7	0.2
Total collections.....	1,039	3	34	96	124	212	1,508	100.0

*P = Permanent, S = Semi-permanent, T = Temporary.

TABLE 3

SPECIES-HABITAT SUMMARY OF SPECIES REPRESENTED BY MORE THAN 10 COLLECTIONS. FIGURES ARE HABITAT INDICES; THOSE LESS THAN 10 ARE EXCLUDED. SOLID LINES SEPARATE SURFACE HABITATS FROM CONTAINER HABITATS AND SURFACE SPECIES FROM CONTAINER SPECIES. DOTTED LINES SEPARATE NATURAL AND ARTIFICIAL HABITATS

	RUNNING CREEKS	CREEK POT HOLES	SWAMPS	PUDDLES	ROCK HOLES	LEAF AXILS	SPATHES AND LEAVES	TREE HOLES	COCONUTS	ARTIFICIAL CONTAINERS	OTHERS
Surface water											
Natural											
Bironella spp.	41	56									3
U. argyrotarsis		41	15	15							28
C. fraudatrix		24	24	16							36
C. squamosus	35	14		45							6
Artificial											
An. farauti	15	13		52							20
C. pullus		11		62						13	13
C. halifaxi		12		64						14	9
C. annulirostris				75							25
An. punctulatus				83							17
A. vexans				92							8
C. papuensis		17		24						39	19
A. novalbitarsis				42	50						8
A. papuensis				26	38					15	21
Water in containers											
Natural											
A. kochi						100					0
A. keefei								91			9
Arm. breinli									94		6
Natural and artificial											
U. papua							33		12	38	16
U. nigerrima							14		29	53	4
A. albolineatus								52	25	15	7
A. notoscriptus								51	13	34	2
Arm. milnensis								18	50	24	8
Toxorhynchites spp.								15	15	68	2
T. bimaculipes								13	13	68	5
A. scutellaris								11	32	45	11
C. fragilis									11	62	26

each of the habitats by locality. It will be noted that:

1. Nearly every habitat was represented at Milne Bay. This locality was the most productive in both species and numbers of individuals. However, since the collection period here was much longer, strict comparison with the other areas is not warranted.

2. Morobe was markedly unproductive largely because natural barriers sharply limited the study area. A light rainfall during the brief collecting period further reduced collection possibilities.

3. Collections from "fresh water in containers" were well represented at nearly every locality, whereas, with the exception of the

ubiquitous puddles, collections from "fresh surface water" had a more scattered distribution. This was directly correlated with the availability of these habitats.

4. Ninety-two per cent of all collections were from fresh water, only 8 per cent from brackish. All brackish habitats were temporary or semi-permanent and were sharply localized. This was due largely to the scarcity and total non-productivity of brackish marshes and swamps. In several areas (especially Gamadodo and Morobe) extensive mangrove swamps were present but mosquito larvae were entirely absent, probably due to a significant daily tidal fluctuation.

5. Seventy-five per cent of the collections were from temporary water, 17 per cent from semi-permanent, and only 8 per cent were from permanent water. Since there was a remarkably high percentage of collections from temporary water, I believe that a significant degree of control could have been achieved by dealing solely with these habitats.

6. Approximately 50 per cent of all collections were from puddles and artificial containers. This figure emphasizes the overwhelming importance of man-made habitats.

Table 3 gives the habitat indices for each fresh-water species represented by more than 10 collections. In each case only habitats with indices greater than 10 are included. It is felt that lower figures represent habitats too rarely utilized to be significant.

The habitats are arranged in a sequence from clear, natural surface water to polluted water in artificial containers. Within this sequence they fall into three major categories, each with its characteristic group of species.

1. In clear, natural surface water, characteristic species were *Bironella* spp., *U. argyrotarsis*, and *C. fraudatrix*.

2. Artificial surface water was almost entirely puddles. Characteristic species were: *An. farauti*, *C. pullus*, *C. halifaxi*, *An. punctulatus*, *A. vexans*, and *C. annulirostris*.

3. In water in containers, characteristic species were: (a) *A. kochi*, *A. keefei*, and *Arm. breinli*, which were found primarily in natural containers; and (b) *U. papua*, *U. nigerrima*, *A. albolineatus*, *A. notoscriptus*, *Arm. milnensis*, *Toxorhynchites* spp., *T. bimaculipes*, *A. scutellaris*, and *C. fragilis*, which were found in both natural and artificial containers.

Very few species bridge the gap between surface and container habitats to a significant degree. Only *C. papuensis*, *A. novalbitarsis*, and *A. papuensis* were frequent in both surface water and in water in containers.

Of the disease vectors, *An. farauti* and *An. punctulatus* occurred primarily in artificial surface water habitats whereas *A. scutellaris* was found primarily in containers.

Habitat Factors

Exposure: In most cases shade or exposure was a natural characteristic of the habitat. For example, tree holes and mountain creeks, by their nature, are shaded, whereas coral pools are exposed. Species with high indices for such habitats showed correspondingly high values for shade or for exposure. In these cases the actual role of this factor could not be determined. However, for several species, exposure seemed significant. *An. punctulatus* and *A. vexans* were common in exposed puddles, whereas *C. annulirostris* was more frequent in shaded puddles. *A. albolineatus* and *C. fraudatrix* were found in a wide habitat range but typically in shaded situations.

Superficial character of water: Based on organoleptic methods, the habitats were divided into four categories: clear, muddy, stagnant, polluted. For the most part, a particular species was not found solely in any one of these categories. This would be expected because of the wide habitat range for nearly every species. However, the following were frequently associated with these water types: Clear—*Bironella* spp., *H. genurostris*, *A. keefei*, and *A. dasyorrhus;* muddy—*An. punctulatus*, *C. halifaxi*, and *C. pullus*; polluted —*Arm. breinli*, *Arm. milnensis*, and *C. fragilis*.

TABLE 4

ASSOCIATION PER CENT OF THE VARIOUS SPECIES. SPECIES REPRESENTED BY LESS THAN 10 COLLECTIONS ARE EXCLUDED AND ALL ASSOCIATION VALUES LESS THAN FOUR HAVE BEEN ADDED AND LUMPED UNDER "OTHERS." READ NUMBERS HORIZONTALLY

	Bironella spp.	*U. argyrotarsis*	*C. fraudatrix*	*C. squamosus*	*An. farauti*	*C. pullus*	*C. halifaxi*	*C. annulirostris*	*An. punctulatus*	*A. vexans*	*C. papuensis*	*A. novalbitarsis*	*A. papuensis*	*A. kochi*	*A. keefei*	*Arm. breinli*	*U. papua*	*U. nigerrima*	*A. albolineatus*	*A. notoscriptus*	*Arm. milnensis*	*Toxorhynchites* spp.	*T. bimaculipes*	*A. scutellaris*	*C. fragilis*	Others
Bironella spp.	68	11	9			4																				8
U. argyrotarsis	5	29	7		10	20	13																			16
C. fraudatrix	7	17	16		26		4	6	7																	17
C. squamosus				43	18	16	6		12																	5
An. farauti		4	5	8	23	21	11	6	16																	6
C. pullus		6		4	15	24	17	4	13		4															13
C. halifaxi		6			11	25	18	6	14		5															15
C. annulirostris					16	16	13	26	16																	13
An. punctulatus				5	15	18	12	6	35																	9
A. vexans						17			25	25																33
C. papuensis		5			5	27	21		5		26															11
A. novalbitarsis												67														33
A. papuensis						8	8		6				36						8			5				29
A. kochi														86												14
A. keefei															36				14			14	8	14		14
Arm. breinli																86		4								10
U. papua																	71		4					5		20
U. nigerrima																9		52	7			6	9	6	6	5
A. albolineatus													5					4	44	6		4	7	11	4	15
A. notoscriptus																5			9	60			5		5	16
Arm. milnensis																					84					16
Toxorhynchites spp.																5			5			52	5	6	5	22
T. bimaculipes		5																11	19	7	5	7	16	14		16
A. scutellaris																			6					73		21
C. fragilis						12	10											4	7	5		4		10	37	11

Vegetation: For most species vegetation was a minor factor since it was entirely absent in 41 per cent of the collections. This is not surprising in view of the temporary nature of so many of the habitats. There was a striking correlation between the type of vegetation and a particular species in only one case: *C. squamosus* was found with vegetation in 85 per cent of the collections and, of these, 61 per cent were with green algae.

*p*H: Nearly every species was found within a wide range. Alkaline readings were relatively few, and for no species was the mode or average alkaline. In general, there was little or no correlation between any one species and certain narrow *p*H values.

Species Association

In Table 4 the species represented by less than 10 collections are excluded and all association values less than four are added and lumped under "others."

Conclusions from this table substantiate those of the habitat table. That is, surface water species have high association values for one another, and, likewise, container species have high association values for one another. The separation of surface water species and container species is quite apparent.

However, as with the habitat groups, there is overlapping. The following, which were found both in surface and container habitats, are likewise found with both surface and container associates: *C. papuensis*, *A. novalbitarsis*, and *A. papuensis*. These three are clearly in an intermediate position.

For almost every species the number of pure collections exceeded the number of associations with any other particular species. *A. kochi*, *Arm. milnensis*, and *Arm. breinli* had the highest values for pure collections.

It is usually stated that predatory species are found more commonly in pure collections. My figures were not unusually high for the predatory species, *Toxorhynchites* spp. and *Culex halifaxi*. Indeed, in the case of *halifaxi*, the value 18 was surprisingly low.

The association of a particular species with any one other exceeded 20 in very few cases. It is believed that the concept of indicator species is in no case substantiated by these data. Examples of the highest associations were: *C. papuensis* with *C. pullus* (27), *C. fraudatrix* with *An. farauti* (26), *C. halifaxi* with *C. pullus* (25), and *A. vexans* with *An. punctulatus* (25).

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News Notes

Dr. Joshua T. Tracey, Jr., Geologic Division, U. S. Geological Survey, has been designated chief of a field party which is undertaking a detailed geological survey of Guam, as a part of the Pacific Geologic Surveys program of the Military Geology Branch. He will be assisted by David B. Doan and Harold G. May.

Simultaneously, Joseph W. Brookhart, Theodore Arnow, and Raymond Chum, of the Water Resources Division, U. S. Geological Survey, are conducting a comprehensive survey of the island's water resources.

To review the existing research and control programs for filariasis and elephantiasis, and to propose further measures for combating them, a conference of medical experts was held in Papeete from August 21 to September 1, 1951. The first international gathering of its kind, it was organized by the South Pacific Commission as part of its program to promote the physical, economic, and social welfare of island peoples in the South Pacific. Nineteen specialists attended, representing Australia, England, New Zealand, Samoa, Tahiti, United States, and Vietnam. Also attending were observers from medical and other institutions in Tahiti.

The three main objectives of the conference were: To define the various problems raised by filariasis and elephantiasis; to determine the research work to be continued or undertaken to solve these problems; and to recommend appropriate measures for the control of these diseases, with special reference to the social and economic conditions of the area.

The conference was opened by His Excellency the Governor of French Oceania, M. Petitbon. Dr. Emil Massal, Executive Officer for Health of the South Pacific Commission, was elected chairman of the conference.

The conference proposed the following recommendations:

The South Pacific Commission should act as a focal point for the area in the collection, collation, and dissemination of technical data relating to these diseases.

Techniques now in use for controlling filariae-carrying mosquitoes should be reviewed and their wider application considered, using specially trained native personnel.

Research now being conducted in Tahiti, Samoa, and Fiji on the control of these diseases by drugs should be continued and intensified.

The Commission should establish a filariae collection of specimens of larvae and adult worms and of microfilariae in human blood samples, arrange for study of this material by parasitologists, and circulate the findings throughout the area.

Detailed recommendations regarding the collection, preservation, and identification of specimens and laboratory diagnosis for microfilariae should be brought to the attention of member governments, territorial administrations, and all private institutions and individuals interested in the problem.

The Commission should act as a clearing house for posters, pamphlets, and other educational material for use in the intensified campaign against these diesases.

The findings of the conference will be considered at the Eighth Session of the South Pacific Commission, which will open at Commission headquarters in Noumea, New Caledonia, during the last week in October.

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